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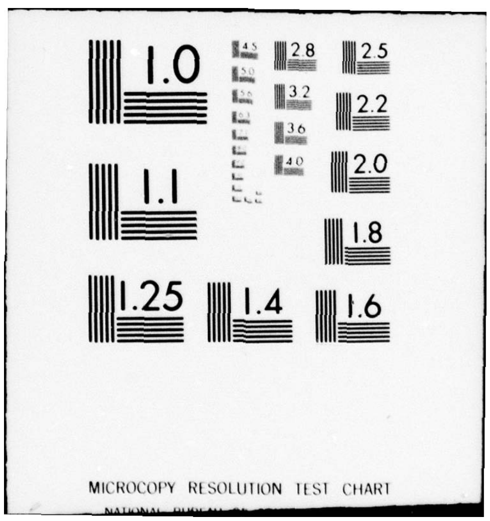
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AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY

VOLUME 1 OF 2

CAE ELECTRONICS LTD.

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The results of a feasibility study for the design of an Advanced Attack Helicopter Flight and Weapons Simulator are reported. Desirable trainer functions have been analyzed resulting in trainer performance requirements. A comparison of available and developmental techniques using performance and cost criteria for selection has resulted in a recommended configuration for the simulator.

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Partial contents of Volume I include: Training Device Requirements; Basic Flight Simulator Design Analysis; Tactical Systems Modules; and Motion Cueing Systems.

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SECTION 1

INTRODUCTION

1.1 STUDY OBJECTIVES

The purpose of the Advanced Attack Helicopter (AH-64) Flight and Weapons Simulator (FWS) Concept Formulation Study was to determine technical feasibility and optimum designs in accordance with the following objectives outlined in Army Regulation 71-1 (Ref. 1-1):

(a) Analysis, comparison, and recommendation of FWS design components based on available technology rather than on experimental effort.

(b) Analysis of trainer performance and operating characteristics.

(c) Trade-off analysis, including economic, trainer efficiency, reliability, maintenance, and integrated logistic support concepts.

(d) Analysis of present designs of other flight simulators as compared with FWS technical approaches.

(e) Cost-effectiveness analysis, including cost estimates of the trainer based on reliability, maintenance, and utilization over the effective life of the trainer.

(f) Estimated time schedules and cost information, assuming design and manufacture of the FWS within the 1978-79 fiscal year period.

Every consideration was taken throughout all stages of the study to ensure that these objectives were attained.

1.2 APPROACH TO MEETING STUDY OBJECTIVES

1.2.1 AH-64 Mission Definition. The first step was to define trainer operating and performance characteristic requirements. Meetings at the U.S. Army Aviation Training School, Fort Rucker, Alabama, at the U.S. Army Armor School, Fort Knox, Kentucky, and at PM TRADE, Orlando, Florida were attended to define the primary role of the AH-64 and the training features most desirable in the FWS. Discussions with the most knowledgeable TADS user at Fort Monroe as recommended by Mr. K. C. Keal at PM TADS and Attack Helicopter users at Fort Bragg, North Carolina, were also held. Information gathered provided the following description of the AH-64 and its primary mission requirements.

Ref. 1-1. Force Development: Army Combat Developments, Army Regulation No. 71-1, Headquarters, Department of the Army, Washington, 16 September 1968.

1.2.1.1 AH-64 Description (Ref.1-2). The AH-64 is a twin-engine, rotary wing aircraft designed as a stable, manned aerial weapons system to deliver point, area, and rocket fires. The crew, consisting of a pilot and copilot/gunner (CPG), sit in tandem, with the CPG in the front seat. The weapons system comprising a turret-mounted 30-mm automatic gun area weapons subsystem, and a 2,75-in folding fin aerial rocket subsystem,operate via the Target Acquisition Designation System (TADS), which has three sighting modes:

(a) TADS head-down display, consisting of infrared, television, or direct optical display capable of various magnifications.

(b) TADS head-up display, showing infrared and television video.

(c) Integrated Helmet-Mounted Display Sight System (IHADSS) capable of inserting video signals and symbology on the pilot and CPG helmet visors.

Direction of weapon fire is dictated by the release angle for the 30-mm gun and 2.75-inch rockets, and by laser reflection or radar/infrared homing for the Hellfire missile. Night operation of the AH-64 is augmented by the Pilot's Night Vision System (PNVS), which is a Forward Looking Infrared (FLIR) video presented on the pilot and CPG visors slaved to either head position. The AN/PVS-5 night vision goggles act as a backup.

1.2.1.2 AH-64 Deployment. The AH-64 will be capable of performing anti-armor operations (direct aerial fire against armor/mechanized forces); air cavalry operations; and airmobile escort and fire support.

We believe the primary mission is operation against armored vehicles in a battlefield situation. Terrain-following flight is used for deployment to attack positions to avoid threat detection. The helicopter must then unmask to gain a clear line of sight to the target, which allows a Hellfire to be guided to the threat. The 2.75-inch rockets can be used to cause heavily armored vehicles to button up or to destroy lightly armored vehicles.

Ref. 1-2. YAH-64 Advanced Attack Helicopter, Vol. 1, System Specification Hughes Helicopters, Culver City, Calif., 1976 (RFP DAAJ01-76R-0374)

1.3 DOCUMENT STRUCTURE

The main body of this study consists of 11 sections. Following this section, Section 2 details training task requirements and is based on contacts with the U.S. Army, Training Task Lists for the AH-1, and Gunnery and Terrain Flying Manuals TC17-17 and FM 1-1. (Ref.1-3 and 1-4).

Sections 3 to 7 present design concepts. Section 3 analyzes basic flight simulation. Section 4 covers the weapons and sighting system. Section 5 deals with the visual system. Section 6 and 7 cover motion cue generation, and instructor facilities respectively. In each of these areas state-of-the-art techniques are examined and designs proposed which most closely meet the requirements of specification, cost and operation. Trade-off analysis described throughout the sections, is primarily based on device effectiveness. In some areas, reliability data is used to choose between devices of equal capability.

The computer interface, memory, and timing requirements are defined for each system in Section 8. Other subjects in Section 8 included investigation of existing 32-bit minicomputers, cost effectiveness of developing operating system, use of FORTRAN IV for real-time simulation programs, memory-type comparison and on-line and off-line diagnostics.

An appreciation of the integrated logistics support for the design and maintenance phases is given in Section 9. Conclusions on components are summarized in Section 10. Section 11 contains the recommended configuration and includes an estimated reliability model, and an estimated procurement cost and production schedule.

Ref. 1-3. Gunnery Training for Attack Helicopters, TC 17-17, U.S. Army Armor School, Fort Knox, 1975

Ref. 1-4. Terrain Flying, FM1-1, Headquarters, Department of the Army Washington, 1 October 1975

SECTION 2

TRAINING DEVICE REQUIREMENTS

2.1 GENERAL

A prequisite to the design of any training device is the determination of required training features. Defining the optimum configuration of a training device requires an initial analysis of the skills training required. Subsequent investigation of alternative design methods and the effect of engineering limitations on the levels to which skills can be taught should determine the final configuration of the training device.

The initial step in investigating training requirements of the AH-64 Flight and Weapons Simulator was to contact the potential users and to determine the following:

(a) A description of the capabilities of the AH-64 helicopter and its proposed operational equipment (AH-64 System Specification (Ref.2-1) and paragraph 2.1.1)

(b) The proposed tactical roles of the AH-64 (paragraph 2.2)

(c) The items of training required for AH-64 crew-members and the areas of training currently existing (paragraph 2.3)

These three items provided a good basis for evaluating the role of an FWS in the AH-64 training program and also provided an insight into areas in which a part-task training device may prove cost-effective.

After a significant amount of data had been collected and a concept formed of the training areas the FWS could best cover, a preliminary training task analysis was produced from which to establish attack helicopter crew training areas. These were used to define areas of simulation needed to fulfill the training tasks and hence, to produce the FWS training device requirements. (paragraph 2.5)

2.1.1 AH-64 Armament. The proposed AH-64 configuration is capable of carrying and delivering 1200 rounds of 30-mm cannon ammunition, up to 76, 2.75-inch folding fin rockets which can have High Explosive Antitank (HEAT) heads or contain smoke or chaff, and can deliver 16 Heliborne Fire and Forget (Hellfire) missiles guided by a laser designator or containing radar/infrared (RF/IR) homing heads.

Ref. 2-1. YAH-64 Advanced Attack Helicopter, Vol. 1, System Specification, RFP DAAJ01-76-R-0374, Hughes Helicopters, Culver City, Calif., 1976

The Target Acquisition and Designation System (TADS) provides the primary method for target detection and weapons release. The system has the capability of acquiring targets through a stabilized sighting system and of presenting optical, black-and-white television and infrared displays to the copilot/gunner. Sighting systems are provided by direct head-mounted sight for both pilot and copilot/gunner, head-up TV display for the copilot/gunner and pilot and a head-down optical, TV, and infrared display for the copilot/gunner. The manipulation of the TADS and its communications with the weapons systems is controlled by the Fire Control Computer (FCC) resident onboard the helicopter. The computer receives direction information from the sights and laser designation and ranging systems and produces directional commands for the firing of AH-64 weapons.

The Hellfire missile system can be used in two modes: autonomous and remote. In the autonomous mode, the laser source designating the target is situated on the helicopter, whereas during remote operation, the laser designator is either ground-based or carried by another helicopter. This means that Hellfire can be fired from a completely concealed position, giving the AH-64 the role of a highly maneuverable firing platform that can be readily deployed to any part of the battlefield area.

Target position information can also be relayed automatically if navigational equipment onboard a scout helicopter is in communication with the AH-64, and the scout carries rangefinding and direction-sensing equipment.

A significant asset of the AH-64 is the incorporation of infrared emission-detecting equipment in the Pilot's Night Vision System as well as the Target Acquisition/Designation System. This should give the AH-64 a significant advantage in nighttime operation.

2.2 TACTICAL ROLE OF THE AH-64

The tactical roles for which the AH-64 was originally intended are as follows:

- Anti-armor operations (direct aerial fire against armor/mechanized force)
- Air cavalry operations
- Airmobile escort and fire support for airmobile operations

Through contacts with potential U.S. Army users and training establishments, we believe that the primary role will be that of antiarmor operations using the Hellfire missile. Another factor that has emerged during the study period is that the AH-64 will probably not be expected to detect targets but will have them identified by either ground personnel or scout helicopter crews.

The techniques involved in completing an AH-64 mission can be split into three areas:

- Flying techniques
- Navigational techniques
- Gunnery and self-defense involving the use of flying and navigational techniques

2.2.1 Flying Techniques. The flight envelope during an AAH mission is dictated by the types of units to be engaged. When in range of threat antiaircraft weapons, it is necessary to keep below their covering radar envelope. In the battle area, visual detection becomes a problem as well, and it must be remembered that enemy tanks can align and fire their weapons within 10 seconds and can have a high-kill probability up to a range of 1500 meters.

Attack helicopters operate in three flight modes while in an operational environment (Ref.2-2)

(a) Nap-of-the-Earth Flight. Nap-of-the-earth flight (NOE) is flight as close to the earth's surface as vegetation and obstacles will permit, while generally following the contours of the earth. Airspeed and altitude are varied as influenced by the terrain, weather, ambient light, and enemy situation. The pilot preplans a broad corridor of operation, based on known terrain features, which has a longitudinal axis pointing toward his objective. In flight, the pilot uses a weaving and devious route within his preplanned corridor while remaining oriented along his general axis to take maximum advantage of the cover and concealment afforded by terrain, vegetation, and manmade features.

Ref. 2-2. Terrain Flying, FM1-1, Headquarters, Department of the Army, Washington, October 1975.

(b) Contour Flight. Contour flight is flight at low altitude, conforming generally, and in close proximity, to the contours of cover and concealment to avoid observation or detection of the aircraft and/or its points of departure and landing. It is characterized by a varying airspeed and a varying altitude as vegetation and obstacles dictate.

(c) Low-Level Flight. Low-level flight is flight conducted at a selected altitude at which detection or observation of an aircraft or of the points from which and to which it is flying is avoided or minimized. The route is preselected and conforms generally to a straight line and a constant airspeed and indicated altitude.

Typical uses of these flying techniques, illustrated in Figure 2-1, evolve throughout a mission, starting with low-level flight at a distance from the battle area to avoid detection by enemy radar. This will change to contour flight at closer proximity to the battle area, the precise point being dictated by distance and terrain features. Contour flying would continue until a holding area is reached where the attack helicopters are deployed to firing positions using NOE flight. Thereafter, the use of NOE techniques will allow the AH-64 to acquire and engage the threat, after which, the AH-64 having released its weapons, it will return to its Forward Area Refuelling and Rearming Point (FARRP), using a profile similar to that of its battlefield approach.

2.2.2 Navigation Techniques. Skills required for AH-64 navigation are variable as a function of flight mode and atmospheric conditions. AH-64 navigational techniques can be divided into two basic areas.

(a) Visual navigation using an ordinance map scaled at 50,000:1 for position reference. At altitudes above the low-level flight levels mentioned in paragraph 2.2.1(c), this involves observation of road, river, and cultural features over a wide area.

At lower flight levels, during contour or NOE flight, the navigation task becomes more difficult. The area under observation by the navigator is effectively reduced, which necessitates the recognition of smaller contour levels and a reduced feature area (e.g., the corner of a wood). Use of variation in vegetation color and type in the proximity of water is an example of the subtlety involved in NOE navigation.

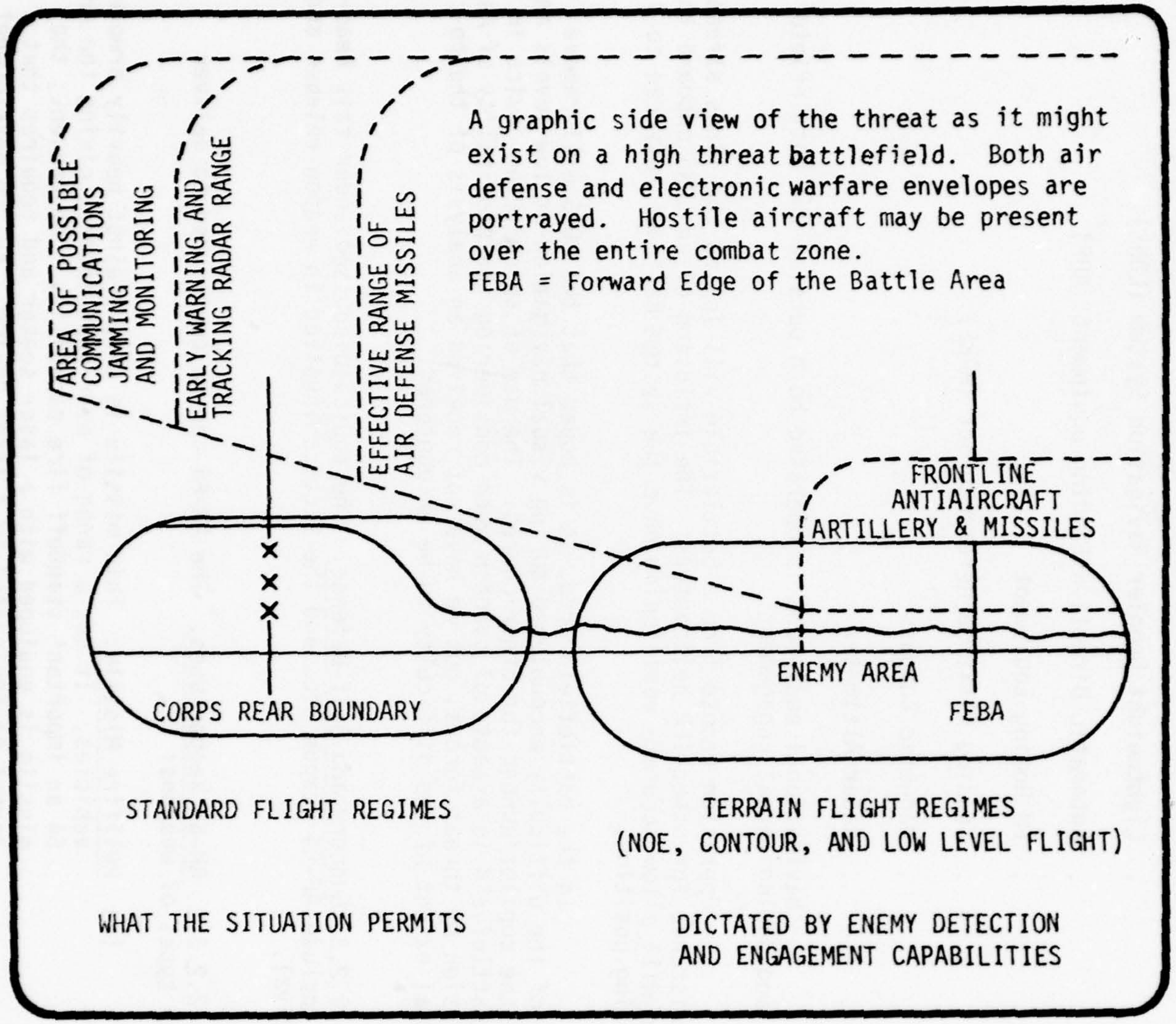


Figure 2-1. Threat Profile

(b) Instrument navigation using airborne equipment and navigational markers. The AAH navigational list includes the following equipment:

- Lightweight Doppler Navigation System (LDNS)
- Automatic Direction Finding equipment (ADF)
- FM Homing Equipment
- Heading Altitude Reference Set (HARS)
- Magnetic Compass
- Radar Altimeter

Navigational equipment is operated both outside the battlefield area and during threat engagement.

Operation remote from a battlefield will follow the lines already in existence for other IFR helicopters. The inclusion of an LDNS onboard the AH-64 will allow accurate positioning once the system has been referred to a starting position.

In the battlefield area, it is hoped that the LDNS will remove some of the difficulty encountered during visual navigation at low levels and free the copilot/gunner for other chores. The use of an emitting device in the battlefield is a cause of concern when considering the possibility of AH-64 detection by threat forces, but we have not received an analysis of the potential extent of the difficulty to be encountered.

2.2.3 Gunnery and Self-Defense. The topics discussed under this heading include AH-64 weapon uses and the tactics involved in weapon release and survival.

2.2.3.1 AH-64 Weapon Uses. The AH-64 can be configured to deliver three types of weapons:

(a) Hellfire Missile. This missile is used against heavily armored vehicles. It has a range of over 5000 meters, giving the AH-64 an important standoff fire capability. At present, the missile is equipped with a laser seeker and requires that a target be designated by a laser device. Future development may include an RF/IR seeker or a TV image seeker. We believe that this is intended as the primary weapon of the AH-64 in its battlefield role.

(b) 2.75-Inch Folding Fin Rockets. These can be used against tanks and lightly armored vehicles. The accuracy of the rockets decrease with distance, requiring enemy engagement of less than 3000 meters. A number of configurations for this weapon are available, including the HEAT (High Explosive Antitank) head and rockets containing smoke or chaff.

(c) 30-mm Gun This weapon is designed for use against lightly armored vehicles and personnel.

Although the Hellfire is the primary weapon system on the AH-64 because of its range and accuracy and although its primary goal is the destruction of heavy armor, we believe that the other weapon systems will be used during engagements. The effectiveness of 2.75-inch rockets onboard the helicopter has been criticized because of their inaccuracy at long range and during hovering and low-speed flight. The rockets become more accurate in diving attacks, but we believe that it will be undesirable to have the AH-64 exposed to enemy fire for any period. The most effective role of the rockets is that of making the enemy button up, thus restricting his FOV to his own display devices (periscopes, etc.) and reducing his ability to spot the AH-64. The 30-mm gun may also be used to counter surprise threats, such as small arms fire during an antitank mission, and may be used against area targets in a manner similar to that of rockets.

2.2.3.2 AH-64 Tactics. The AH-64 tactics used in destroying armed vehicles can be split up into two areas:

(a) Direct engagement, where the Hellfire missile is guided by the AH-64 laser designator.

(b) Indirect engagement, where the Hellfire missile is guided by a remote laser designator.

2.2.3.2.1 Direct Engagement. To engage targets directly, the AH-64 must be able to view a target through the target acquisition/designation equipment or with the naked eye.

Discussions with the U.S. Army have revealed that exposure of the AH-64 to enemy threat will be limited in every possible way. The helicopter will not be used to detect targets on the battlefield, but will be guided to a firing position and told the proximity of a target by a scout helicopter.

The following discussion describes our understanding of the tactics used by the AH-64 in destroying enemy armor in an offensive and defensive situation.

The primary difference between the two situations is that when the AH-64 is used in an offensive or counteroffensive role, the position of the threat armor is not likely to be known accurately. In this situation, the scout helicopter must detect the targets and guide the AH-64 to a firing position. When defending against a threat offensive, the position of the enemy is more obvious, and the AH-64 will be able to position itself at a vantage point, using information from a scout, then unmask and select the priority targets from those in view. The problem of detection is made simpler because the threat is moving rather than static.

In the offensive role, therefore, the scout helicopter is responsible for all of the AH-64 movements in the battle area. In the defensive role, the role of the scout would diminish, although we feel it would be expected to perform an overview of the battle area and provide information on best areas for attack and the position of enemy retaliatory vehicles (Hinds, ZSU's, etc.).

We believe from our discussions with the Army that a difference in flying techniques may be involved because of the greater expectancy of rifle fire when attacking an enemy defensive position than when defending against an enemy attack. In the latter case, one would expect the enemy armor to precede rifle units.

A typical AH-64 mission in an offensive role would involve a briefing of the overall tactical situation prior to takeoff from a Forward Area Rearming and Refuelling Point (FARRP). The AH-64 would proceed to a rendezvous area with the scout helicopter, using the flying and navigation techniques mentioned in paragraphs 2.2.1 and 2.2.2. Normally, two AH-64's and one scout would form a typical unit which would proceed, using NOE flight with the scout leading, to firing positions against the threat armor. Surprise attacks enroute to these firing positions could be engaged, using rockets or 30-mm bullets.

When in firing position, the scout would perform a 'handoff', giving the approximate range and direction in which the target is located. With this information, the AH-64 would 'pop-up' to a position giving a direct view of the target and would acquire the target, using the TADS sighting system at a low magnification setting. As soon as the target is acquired, the TADS sight magnification would be raised to give a larger picture, the laser designator would be employed, and a Hellfire missile released.

It is important that the missile laser seeker receive signals during the latter phase of flight, and so the AH-64 would have to remain unmasked until the Hellfire impacted with the target, which could be for a period of up to 10 seconds at 5000 meters. After target destruction, the AH-64 would remask, move quickly to avoid any retaliatory action, and wait for the scout to guide him to another target.

The preceding discussion has covered tactics in an AH-64 offensive role. In defending against a threat attack in such an area, we assume that the role of the scout helicopter would diminish, and the AH-64 would assume the responsibility of target identification, from which the crew would decide which targets should be attacked first. Communication among AH-64 crews and scout helicopters would be used to ensure that no one target is attacked by more than one AH-64. In this role, the AH-64 is still expected to minimize the risk of retaliation by remaining hidden from the enemy while not actually firing weapons.

2.2.3.2.2 Indirect Engagement. The Hellfire missile is designed to seek reflected laser light that can be generated from a remote source. This allows weapon release in a relatively secure area and involves precoding the missile seeker to home on a specific laser reflection and release of the weapon inside a certain corridor so that the seeker will scan the correct area.

The indirect mode depends heavily on the use of communications, either by voice commands between the AH-64 crew and the designator operator or through a digital link between the AH-64 fire control computer and the designation equipment giving the position of the target.

2.3 ATTACK HELICOPTER CREW TRAINING REQUIREMENTS

The training areas needed to produce a fully integrated attack helicopter crew can be split into the following four areas:

- Basic training in helicopter flying and navigation
- Transition training for the AH-64
- Weapon training
- AH-64 mission training

The following paragraphs describe each of these areas, in turn showing what skills are required, how training is presently implemented, and what type of training device is best suited to give effective training in each area.

2.3.1 Basic Training

2.3.1.1 Flight Training. The initial training of a helicopter pilot involves developing the skills necessary to perform basic rotary-wing maneuvers such as takeoff, hover, and landing, progressing to NOE and contour flight. Current training in this area involves small, low-cost helicopters such as the OH-58 to teach the basic flying skills common to all rotary-wing aircraft.

We do not believe that this area of training can be effectively carried out using a synthetic training environment, although the ability to perform all the maneuvers involved must be included in a helicopter simulator.

2.3.1.2 Navigation Training. As discussed in paragraph 2.2.2(a), visual navigation at NOE altitudes presents a significant problem. The subtleties involved in navigation where a crew member is presented with a view over a restricted area require the recognition of small contours as well as variations in vegetation.

A system of instruction for visual navigation training called Map Interpretation and Terrain Analysis Course (MITAC), originated by Dr. J. Bynum of the Army Research Institute (ARI), Fort Rucker, is currently in use by the U.S. Army. The system involves scanned scenes of NOE environment projected onto a screen to give the student a 90^{o} field of view (FOV). The course is self-pacing and interactive and has been credited with doubling the low-level flight speed performance in the past two years.

As in the case of flight training, we do not believe that navigational training should be performed in a full simulator, although the difficulties involved in navigation should be present during mission training.

Route planning requires a high degree of skill in map interpretation and must be performed before each mission. Evaluation of the chosen route could and probably will be done in the simulator; however, the frequency of exposure to enemy fire might depend as much on the ability of the pilot as on the chosen route. The practice and evaluation of route planning is probably best performed in the classroom. The trainee might benefit from a form of computer-aided instruction that could automatically evaluate his route from the point of view of exposure to the enemy, length of route, difficulty of route, etc.

2.3.2 Transition Training

2.3.2 Transition Training. Transition training on the AH-64 will involve teaching helicopter crews with previous flying experience the following characteristics of the AH-64:

- Flight characteristics

. Navigation equipment

. Communications

. IFR flying

. Use of checklists

. Operation during normal and abnormal conditions

Transition training does not involve mission against a threat force but is designed to instruct crews fully in the operation of the AH-64.

Transition training presents a good area for the use of flight simulators for complex aircraft such as the AH-64. Since the running costs of the AH-64 are expected to be $1030/hour, the purchase of a simulator is easily justifiable for this training alone. However, the requirements of transition training are not as demanding as those of mission training, and it may be that the purchase of a less costly simulator for transition training is more economical.

Another point in favor of a low-cost transitional trainer is the likely high number of crews to be transitioned to a helicopter not yet in production and therefore not available for training.

2.3.3 Weapon Training. The acquisition of shooting skills is probably the most expensive part of AH-64 training. The cost of one round of 30-mm ammunition is $8, and one Hellfire missile costs about $10,000. We believe that a considerable amount of practice will be required to become proficient in using the TADS, weapon sighting systems, and weapons themselves. A certain amount of practice will also be required on a continuing basis to maintain the gunners and pilots in a battle-ready condition. Target detection is often associated with weapon training; however, as with navigation training, this still requires a high level of acuity which the simulator cannot provide. In an NOE environment, it becomes a pattern matching problem which can be taught or practiced in the classroom.

The target detection process can be thought of as a stimulus that triggers a certain response, usually involving the firing of a particular weapon. On a training device, the visual display would have to be able to provide a sufficient level of stimulus to trigger the correct response. It would also be important for the gunner to be able to evaluate the damage to the target in order to determine what further action should be taken.

2.3.4 AH-64 Crew Mission Training. AH-64 crew mission training represents the area in which basic flying and navigation skills, knowledge of the AH-64 characteristics, and procedures and the skills in weapons delivery are all brought together against a threat force. The pilot and copilot/gunner must learn to act as a team in employing techniques to acquire a target, destroy it, evade retaliatory measures after weapons release, and move about the battle area. Appendix B lists the skills presently required of attack helicopter crews and is an excerpt from the Gunnery Training Manual for Attack Helicopters produced by the U.S. Army (Ref.2-3).

Present mission training is conducted largely by operating helicopters against stationary targets. The introduction of moving targets creates extra expense in machinery and manpower. The introduction of Simfire currently in use in European countries can be expected to reduce the cost of weapons, but a high basic cost of helicopter operation and manpower will still remain.

Crew mission training is the area we believe the AH-64 flight and weapons simulator can best fulfill. We feel that stimulation of the correct responses required throughout a complex mission can best be developed in a realistic environment with which a crew can interact. This will allow a crew to develop the teamwork necessary to operate successfully in a hostile environment.

2.4 TRAINING DEVICES

2.4.1 Flight and Weapons Simulator. During the study program, we undertook an AH-64 training task analysis which we hoped would help us in defining a simulator to cover all training items. As the study progressed, we began to realize that although we may produce a trainer to cover all training areas, a prime consideration in our design efforts must be the use to which the trainer would be put because of the restrictions of the amount of simulator time available to each AH-64 crew. Five hundred hours per month is about the maximum usage of a simulator, and if we consider an AH-64 unit with an assignment of 200 crews, each crew will receive two to three hours a month of simulator time. This means that less than three hours of training per month could be dedicated to either transitional training or full mission training.

Ref. 2-3. Gunnery Training for Attack Helicopters, TC17-17, U.S. Army Armor School, Fort Knox, 1975.

Figures we have received on the costs of operating the AH-64 indicate that running costs for the helicopter are estimated at $1030/hour. This figure represents the costs involved in transition training, during which no weapons are fired. The cost of weapons involved in an AH-64 mission is high, with one Hellfire missile priced at $10,000. On the basis of these figures, it appears that using the FWS for training in which a crew does little else but engage targets during a training session is more cost effective than conducting transition training. This is not to say that transition training would not be cost-effective, since we believe it certainly would be, but rather that the procurement of a number of transitional trainers would produce greater savings in aircraft operating costs and would allow the FWS to be used purely for mission training.

We believe that accurate simulation of aircraft systems and flight handling satisfy the IFR (Instrument Flight Rules) training requirements necessary for transition to the AH-64. It then remains a visual system problem to introduce VFR (Visual Flight Rules) transition training and mission training, and as such the visual system is the single most important component of the FWS.

The benefit of a mission trainer is in placing AH-64 crews in an interactive tactical situation which they would not experience with current training techniques and is, in our opinion, the primary use for a flight and weapons simulator.

2.4.2 Supplementary Trainers. We believe that a requirement for a full mission simulator does not preclude the use of a trainer or trainers dedicated to teaching specific training areas. Such training should be self-instructional as much as possible.

Training on the TADS, for example, may lend itself easily to a trainer involving only the TADS equipment, some image generation equipment, and a computer controller. The cost of such a device will be significantly less than that of a full mission simulator, and gunners could be trained effectively in the use of TADS to raise their level of skill and to keep them in the battle-ready condition.

The IHADSS may also be a candidate for a part-task trainer.

Another candidate for part-task training is a route planning trainer such as that mentioned in paragraph 2.3.1.2. A computer driven evaluation of a trainee's choice of route into a hostile area where he must keep hidden could be used as a classroom tool.

A transitional trainer for the AH-64 pilot's station appears to be justifiable in terms of cost. Such a trainer need have no out-of-the-window visual display but could have a visual system driving the PNVS to allow training in IFR and infrared visual flight. All other transitional training, such as checklists, communications, and normal and abnormal procedures, could also be practiced.

Further study is required to ascertain the amount of training necessary to become proficient in areas such as weapon training, use of TADS, route planning, target detection, transition training, use of IHADSS and also the amount of training required to remain proficient in these areas. This will enable part-task trainers to be designed in the most efficient manner and to ensure that they complement the role of the mission trainer.

2.5 AH-64 FWS TRAINING DEVICE REQUIREMENTS

The following paragraphs describe the FWS training device requirements we consider to be of prime interest. Our opinions in this area were based on discussions with U.S. Army personnel and a review of their manuals.

In the AAH training task analysis (Appendix A), we used the AH-1 task list as supplied by the U.S. Army Armor School at Fort Knox and amended the items, using informed estimates of AH-64 mission (paragraph 2.2) and information about the AAH equipment configuration.

After listing the tasks, it was necessary to define into which areas of training each task could be broken. The areas chosen were selected to fit easily into the building blocks for AH-64 simulation, with the instructor's involvement included to highlight instructor loading in particular training areas. The areas selected were as follows:

(a) Basic flight simulation, which includes the areas common to standard CAE simulator production. This includes aircraft handling, engine and ancillary simulation, flight controls, navigation and communication equipment, audio simulation, and cockpit instruments and controls associated with these areas.

(b) Motion cue generation to provide a representative motion cue reflecting vibration and aircraft acceleration levels.

(c) Visual system, which includes out-of-the-window scene description, scene content and video associated with helicopter tactical displays, and night vision aids.

(d) Tactical system, which covers all weapons release systems, manipulation of TADS, and usage of the Fire Control Computer (FCC).

(e) Instructional involvement, which itemizes areas of trainer control over the complete mission spectrum.

Each simulation area was composed of a group of elements (Appendix A), and subsequently the elements were assigned to training tasks to give the simulation requirements to train for each task. Since the properties required of an element may differ from task to task, the introduction of relative task importance was required to decide which properties are most desirable in areas where incompatible properties are requested. The final stage was produced as a result of involved discussion used to produce the task analysis in Appendix A and is reproduced in summary form in the following paragraphs and referred to in detail in Sections 3 to 8.

The most important area of training for the AH-64 FWS is the integrated crew mission training and relative task importance differences were resolved by reference to this criteria. When considering this, however, we took into account that the AH-64 mission may change over a period of time and the FWS must be sufficiently flexible to absorb these changes. It is our belief that navigational training through the MAITAC system is effective, and the importance of visual navigation in the FWS is of low priority. Data gathered at Fort Rucker also indicates that basic flight training can be achieved by using a less expensive helicopter than the AH-64, and it is our opinion that such training, once learned, can be applied to any helicopter.

2.5.1 Basic Flight Simulation. Basic flight simulation includes the basic systems that comprise a training environment sufficient to train crews in:

- Flight
- Navigation
- Communication
- Engine system management
- Ancillary system management
- Equipment malfunction procedures
- IFR flight

Little development in simulation techniques is needed in these areas, since such training is afforded in CAE helicopter simulators already installed, such as the UH-ID and CH-53, through the incorporation of the following items:

- Detailed flight control and flight model simulation capable of operation throughout the complete flight envelope.
- Accurate representation of all aircraft parts and instruments in the simulator flight deck.
- Accurate reproduction of engine and ancillary system effects for normal and abnormal operation.
- Simulation of radio stations over any part of the world's surface.
- Correct navigation equipment effects.
- Aircraft noise reproduction in the trainer cockpit.

Areas of development required to meet AH-64 performance requirements are discussed in the relevant parts of Section 3.

2.5.2 Motion Cue Simulation. The AH-64 is a high-performance aircraft capable of generating high accelerations, particularly in the vertical axis. At the same time, the aircraft will experience vibrations due to rotor engine and gearbox effects. Accurate reproduction of the amplitude and duration of the motion cues greater than those previously required for CAE helicopter simulators operating inside their normal operating envelope is required. The effect of this on motion cue generating equipment is discussed in Section 6.

2.5.3 Visual System Requirements. The visual system represents the single most important area of the simulator. The AH-64 operates in its primary mission in an almost total visual environment. Both crew members have a large FOV horizontally and with lateral head movements can obtain a large vertical FOV downwards. The necessity for a large vertical FOV (greater than 50°) is doubtful, since the pilot tends to look towards the horizon and the direction in which he is going for obstacles at the helicopter height rather than down at the ground. As recommended in paragraph 5.2 dealing with FOV, experimental data is required in this area.

The scene detail required for the visual display has been described at Fort Rucker as sufficient to allow terrain flight but not necessarily to train for terrain flight. This means a large amount of detail is necessary in the scene to provide sufficient visual cues to enable a pilot trained in terrain flight to fly NOE.

The playing area should be large enough to allow the crew to develop visual navigation techniques while flying NOE.

A playing area of 7 x 15 km has been described as adequate at Fort Knox and a total playing area of 20 x 40 km desirable. A number of different terrain types is preferable, with European and desert the dominant requirements.

The insertion of targets into the visual scene is required to train in close engagements using rockets and cannons but is of doubtful necessity in the missile firing situation. Target acquisition is primarily done by scout helicopter, and the AH-64 is directed to a firing position and told the direction of the target. Subsequent acquisition by the AH-64 is done through TADS with the pilot being directed by the copilot/gunner. The effect of weapons detonation, such as smoke plumes is desirable to allow the pilot to evaluate when to mask after missile firing and to know when he is under fire.

Production of the TADS video should include presentation of moving targets on both TV and optical pictures. Simulation of FLIR scenes is also necessary for PNVS training and TADS FLIR training. The method of simulation should be geared to elicit the correct response from the student in his choice and management of equipment.

The AH-64 uses night vision goggles as a backup to the PNVS. This requires that variable light levels be present in the main visual scene to allow realistic operation of the goggles in the simulator.

Visual display generation equipment requirements and capabilities are discussed in Section 5.

2.5.4 Tactical Systems. Tactical systems simulation requirements involve the operation of weapons sighting systems and the effects of weapons release. The trainer must include an accurate representation of the effects of all controls on weapons release and guidance. The results of the handling of all controls by the trainee should be accurately reflected in his simulated kill capacity. A realistic visual presentation for the TADS is required to allow sighting of weapons systems, and the effect of aligning the IHADSS with the main visual display must also be realistically modelled.

The tactical system discussions are contained in Section 4.

2.5.5 Instructor Capabilities. The instructor capabilities required are dictated by the nature and density of tasks required prior to and during a training mission. From the task analysis it is apparent that the instructor's involvement in communications is the predominant requirement during exercises. He must also have the capability of inserting malfunctions, monitoring student progress, monitoring the progress of the mission, and controlling the operating environment. To coherently execute those functions in a training mission sequence, he must have a detailed plan of events prior to the mission.

The design development for these requirements is the subject of Section 7.

SECTION 3

BASIC FLIGHT SIMULATOR DESIGN ANALYSIS

3.1 INTRODUCTION

This section describes the basic flight simulator required to provide a synthetic training environment for instructing AH-64 crews in flying techniques, instrument navigation, communications, engine and system management, and normal and emergency checklist procedures. The following areas are covered:

- Flight deck
- Primary flight controls
- Instruments and secondary flight controls
- Flight simulation model
- Navigation and communications systems
- Propulsion and ancillary systems

Other modules such as motion, visual system, tactical systems are integrated with the basic flight simulator to form the complete Flight and Weapons simulator.

3.2 FLIGHT DECK

3.2.1 Configuration. In this area, two alternatives were considered:

(a) One flight compartment with the two crew members seated in tandem, as in the AH-64.

(b) Two separately mounted flight compartments, one for each of the two crew members.

The use of a single flight compartment has several important disadvantages:

- The difficulty of arranging an adequate front visual display (Section 5) for the pilot.
- The inflexible nature of the visual configuration does not lend itself to future changes to reflect advances and improvements in design.
- Entrance to the front cabin is awkward with a wide angle visual display in place.
- Instructor monitoring of the first crew member cannot be done directly as discussed in Section 7.
- Difficulty of accessibility for maintenance purposes.

The two cockpit configuration solves all of the above problems but in itself has several disadvantages:

- Extra cost of second motion base and other structures.
- Two instructors stations are required.
- Makes the use of real aircraft cockpit shells uneconomical as explained in paragraph 3.2.2.
- The flight controls must be back driven under computer control rather than mechanically linked.

An advantage of the two cockpit arrangement is the capacity to train two crew members independently. The pilot may practice take-offs and landings while the copilot/gunner can undertake gunnery practice.

CAE believes that the principal factor influencing the choice of FWS cockpit configuration is the vertical visual display mounting. The configuration of the display recommended in Section 5 consists of a 12-foot dome surrounding each pilot. Although the use of pancake window displays instead of a dome would allow the use of one flight compartment on one motion base, the flight compartment would have to be modified to locate the pilot's visual display. These modifications would probably interfere with cockpit instruments and controls. Furthermore, a dual cockpit with pancake window displays would add about two tons to the simulator weight and would probably require a larger and more expensive motion base. For these reasons, CAE believes that the extra complexity, involved in two motion bases, and flight control modifications, is justified.

3.2.2 <u>Cockpit Shell Construction</u>. There are usually two options for simulator cockpit shells:

(a) Use of real aircraft shells

(b) Fabrication of a substantially simplified structure by the simulator manufacturer.

Both types have been used in CAE helicopter simulator production, depending on economic considerations. In the case of the AH-64 separate cockpits for pilot and CPG would require extensive and different modification to the aircraft structure for each of the two visual display configurations. For this reason, fabrication of the flight compartments by the simulator manufacturer is recommended.

Since cockpits are not aircraft parts, there is a choice of basic construction methods and materials. The relative merits of reinforced plastics versus light metal alloys were considered and it was decided that fabrication from light metal alloys was superior to reinforced plastics. This choice provides greater strength and stiffness for rigid mounting of internal and external simulator hardware such as control force units and displays. Nonmetalic materials such as thermosetting plastic laminates would be used only as linings or coverings in areas where structural strength is not critical.

3.2.3 Cockpit Base Frame. The base frame and mounting structures can be fabricated from rolled steel or extruded aluminum sections.

3.2.4 Ventilation and Cooling. In a training device, comfort cooling for occupants requires removal of body heat as well as any equipment heat which cannot be isolated from the cockpit air mass.

All heat dissipating equipment such as instruments, amplifiers, displays, etc., are isolated from the cockpit interior air mass to the greatest extent possible. Cooling can be effected by the intake and discharge of room ambient air by natural or forced convection as required. If the trainer is installed in an air controlled environment room, comfort cooling can be achieved by circulation of room air in the cockpit without additional cooling.

If comfort cooling cannot be attained by this means, additional cooling can be provided using a cockpit mounted cooling coil supplied with refrigerant from a remote source to condition room ambient air for cockpit use. Air circulation can be provided by a low pressure, low noise level circulating fan using the aircraft supply ducting and additional ducting as required to obtain sufficient flow at low static pressure. The cooling coil must be designed to prevent icing at low air flows and the condensate is drained off or pumped to a remote point.

Temperature control can be attained via a sensor and electronic network located in the cockpit which supplies electrical signals to control the flow of the refrigerant, thereby enabling proportional and continuous control of temperature. The isolation of equipment and occupant environment permits cooling air to enter at a relatively small temperature difference and reduces discomfort caused by high velocity cold air blasts from small outlets. In a trainer operated with the canopy open or with the windshield or other large transparencies removed, the occupant comfort cooling becomes principally dependent on room ambient air conditioners.

The air velocities, temperatures and other parameters of the aircraft Environment Control System (ECS) are not duplicated in the trainer. Simulation is limited to effect of ECS system on other systems, e.g., effect of bleed air on engine performance.

3.3 PRIMARY FLIGHT CONTROLS

Flight controls represent the primary interface between the pilot and his aircraft. The controls require careful simulation if aircraft handling characteristics are to be reproduced. Primary flight controls employed on the AH-64 are as follows:

- Fore and aft cyclic control
- Lateral cyclic control
- Directional pedal control
- Collective pitch control

Both the pilot and the copilot/gunner have a complete set of controls which are mechanically linked, with the pilot having overriding control. A switch mounted in the crew compartment allows the mechanical link to be disengaged.

Three different techniques have been used by CAE to simulate the force feel characteristics of helicopter controls:

3.3.1 Use of Aircraft Components. In cases where aircraft components are available at a reasonable cost, the complete servo system up to the output linkages from the mixer unit is installed. This approach ensures fidelity of simulation. Jamming failures are simulated using clutches or brakes downstream of the mixer unit. The use of the aircraft system ensures interaction between controls in the event of hydraulic or jamming failures and is consistent with the aircraft. In the case of the AH-64 simulator, this approach is precluded by the separation of the pilot and copilot/gunner onto two separate motion bases.

3.3.2 Simulation of Aircraft Components. In some cases it proves economical to construct servos which are similar to the aircraft parts. A combination of aircraft linkages and manufactured equivalents is used to construct this system. This approach is also precluded by the separation of the pilot and copilot/gunner.

3.3.3 Active Load Units. The third simulation technique, that is proposed for simulation of the AH-64, is the use of a servo driven actuator to position the control stick in response to measured force inputs. Recent developments at CAE have led to the design of a hydraulic actuator with hydrostatic seals at both piston and rod end which essentially eliminate friction and stiction effects. The reduction of these effects permits the use of a high gain force servo loop with sufficient bandwidth to simulate all control stick characteristics including hard stops. An electronic compensator is designed for the basic servo loop to provide a wide bandwidth while ensuring stability. A strain gauge force transducer with good stiffness and resolution characteristics is used to provide a force feedback signal.

The position of the pilot's stick is sensed by a LVDT transducer and the resulting signal is operated upon by an analog model of the aircraft stick's dynamic characteristics to produce a command signal for the force servo. In this way a basic spring gradient together with viscous and inertial effects, viscous friction, and coulomb friction are generated. All of these terms are readily adjustable. Computer inputs are used to modify the basic force gradient in response to changes of airspeed or altitude and to simulate failures.

Since the pilot and copilot controls are physically separated, the mechanical linkages of the aircraft must be reproduced by the force servos. A force servo for each control will be duplicated, one identical version for each station, however, a single analog model will be used. A large spring stiffness operating on the position difference between the two sticks will be used for synchronization. This circuit will be inhibited in the Back Up Control System (BUCS) mode. Automatic Stabilization Equipment (ASE), if capable of moving the flight controls, will also be simulated. The basic recommended control system is shown schematically in Figure 3-1. Similar systems can be used for cyclic, collective throttle and yaw. To finalize the design, additional information is required on the effects of jamming or hydraulic failures, particularly with respect to interaction between controls through the mixer unit. In addition, detailed drawings of the linkages and available space are required as rigidity is essential to the performance of the force servo.

3.3.4 Commercially Available Load Units. McFadden Electronics currently produce complete control force units for use in flight simulators. We feel that their systems are expensive and difficult to tailor to specific requirements. In addition they are not constructed from standard aircraft components and do not provide realistic looking controls. In view of the available design capacity at CAE and compatability with CAE software there would be no advantage to subcontracting the control force load units.

3.3.5 Flight Control Vibrations. High frequency vibration of controls, if required in conjunction with the seat shaker for added realism, can be provided by digitally controlled oscillators within the control force load unit analog model.

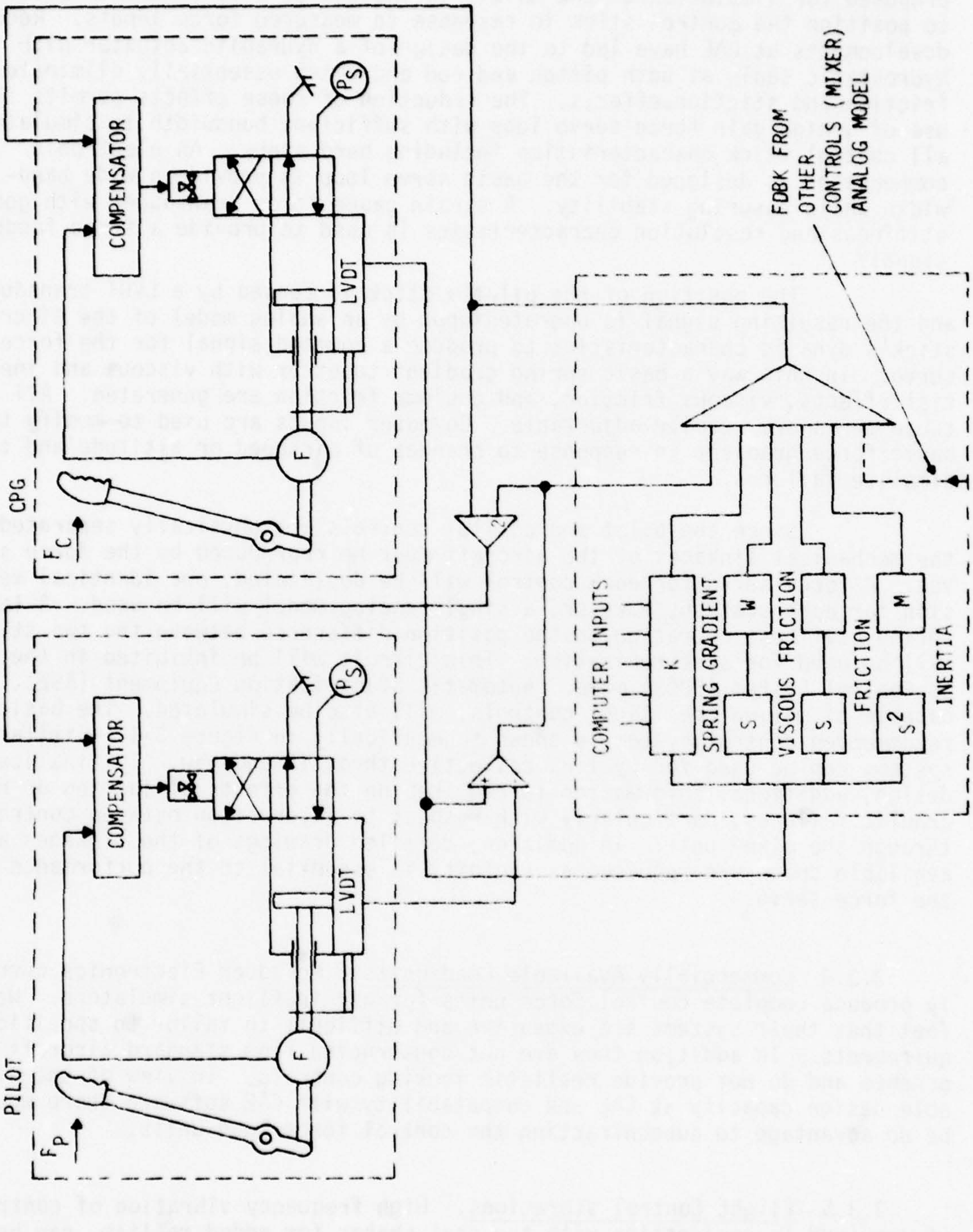


Figure 3-1. Simplified Control Loading Schematic

3.4 INSTRUMENTS AND SECONDARY FLIGHT CONTROLS

3.4.1 General. The current policy at CAE is to use original aircraft instruments in the trainer to simplify instrument procurement, maintenance and provisionings of spares for the customer. The use of an aircraft instrument requires fulfillment of all the following conditions:

(a) The instrument is electrically driven and the input signal is one of the following:

. 3-wire synchro

. DC

. 400 Hz ac

. Digital signal

(b) The instrument does not contain compensating devices or other components which may adversely affect the accuracy or reliability when used with the computer interface.

(c) The instrument is not driven from variable resistance, capacitance or inductance transducers.

If the input voltage or power requirement exceeds the interface output voltage or power capability a dc amplifier may be connected between the analog output and the original aircraft instrument. To retain original 400 Hz instruments 400 Hz modulators may be used. Simulated instruments have the original instrument front end components, dials, drums, pointers and bezels, but a different actuating mechanism is used in place of the original. They also have at least the same standard of reliability and maintainability as original aircraft. The avionics control panels used in CAE simulators are generally unmodified original aircraft parts. Other panels are original panels but generally rewired in the simulator.

3.4.2 AH-64 FWS Instruments and Control Panels. The AH-64 instruments, displays and control panels are itemized in the Advanced Attack Helicopter System Specification (Ref. 3-1) and have been listed in Appendix G. Most of the instruments listed can be found on many helicopters presently in use and should present no simulation problem. A number of instruments and displays were developed especially for the AH-64 and do not fall into this category. They are as follows:

Ref. 3-1. YAH-64 Advanced Attack Helicopter, Vol. 1, System Specification, Hughes Helicopters, Culver City, 1976 (RFP DAAJ01-76-R-0374).

- Electronic Attitude Director Indicator (EADI)
- Doppler control panel and display unit AN/ASN 128
- Remote doppler control/display unit
- Radar warning display AN/APR - 39(V)1
- Integrated helmet display sight system
- Gunners video/status head-up display
- Gunners video/status head-down display

In the case of all the systems mentioned above CAE recommends the development of special interfacing to the aircraft instruments enabling these aircraft parts to be installed in the trainer. None of these displays apart from the radar warning display are presently in existence and data on signal interfacing is available in specification form only. There is also a connection among the displays, apart from radar warning, through the Fire Control Computer (FCC) which CAE recommends for integration into the simulator.

Further detail on the FCC and the type of interfacing between it and displays can be found in paragraph 4.2. In the simulator it is intended to use AH-64 panels whenever possible.

3.4.3 Cockpit Controls. Simulator controls other than primary flight controls are, wherever possible, aircraft parts e.g., throttles, canopy opening and locking controls. Where a representative control load is required which cannot be supplied through the installed unit a feel can be induced by means of spring force, mechanical or electromechanical friction units or viscous loading devices.

3.5 FLIGHT SIMULATION MODEL

3.5.1 Introduction. The flight model is the heart of the simulation from which the flight instrument, the visual and motion system commands are initiated. It is therefore very important to the training effectiveness of the simulator that an accurate aerodynamic model of the helicopter over the whole of the training envelope is programmed in the software. Such an aerodynamic model is dependent mainly on the quality of aerodynamic data available. This means the data requirements are one of the most important factors

in the flight modelling of this training device. It is not known to what extent data will be available at the time the simulator contract is awarded. It is recognized that there could be considerable gaps since the aircraft is a relatively new design. The problems of obtaining simulator data and of dedicated aircraft flight tests are referred to by Woomer and Carico (Ref.3-2) and Gerlach (Ref.3-3). As each topic is referred to in the subsequent paragraphs the data requirements are also discussed.

The helicopter flight model encompasses the following areas:

- Equations of motion
- Total force and moment calculations
- Flight instrument response
- Atmosphere, wind and turbulence modelling

The resulting flight model computation will provide data for the motion system and visual system drive equations, as well as navigation and height data. The inputs to the flight model will be crew control position parameters, engine torque, and rotor speed, with additional effects of weapon firing, enemy hits and instructor controlled malfunctions. It is also important that the flight model operates in real time scale with a minimum of data transmission delays to and from other modules. For the design of the flight dynamic model, CAE can draw on its wide experience of flight simulation in eight UH-1D simulators with motion, two CH-53 simulators with motion and two CH-47 simulators with motion, one of the latter with an extensive visual system. These trainers have provided CAE with experience in flight modelling of:

- Small helicopters with a Bell stabilizing bar rotor system
- Conventional and twin rotor helicopters over a wide range of power to weight ratio
- Three different forms of landing gear
- A variety of automatic stabilization equipment systems

Ref. 3-2. Woomer, C. and Carico, D., A Program for Increased Flight Fidelity in Helicopter Simulation, Proceedings of the 33rd Annual Forum of the American Helicopter Society, Washington, May 1977.

Ref. 3-3. Gerlach, O. et al., Approach and Landing Simulation, AGARD-R-632, October 1975.

. A limited amount of low speed flight

. Some terrain contour modification of the wind profiles

The AH-64 will probably produce new problems in the field of helicopter modelling for simulation training. These can be grouped as follows:

. The effect of wing with flaps

. The high thrust/weight capability of the main rotor

. The requirement for low speed flight accurately in any direction

. The effect of topographical obstacles on local wind direction and turbulence

3.5.2 <u>Flight System Analysis</u>. In this section, the functions of the flight model in relation to other simulation modules are considered, and the techniques that are necessary for successful implementation of the flight model are presented. The major input/output relationships are depicted in Figure 3-2 and various submodules are described which together constitute the flight dynamics model.

3.5.2.1 <u>Input Parameters</u>. The flight model requires an array of input parameters which generate responses through the model, and which result in a modification to the output parameters. The input parameters are generated by:

. Crew (pilot or copilot/gunner)

. Instructor

. Tactical situation module

The input parameters can be further divided into three categories as follows:

. Continuously variable inputs

. Discrete inputs

. Keyboard discrete inputs

These are shown in Figure 3-2 and are discussed below for each input source.

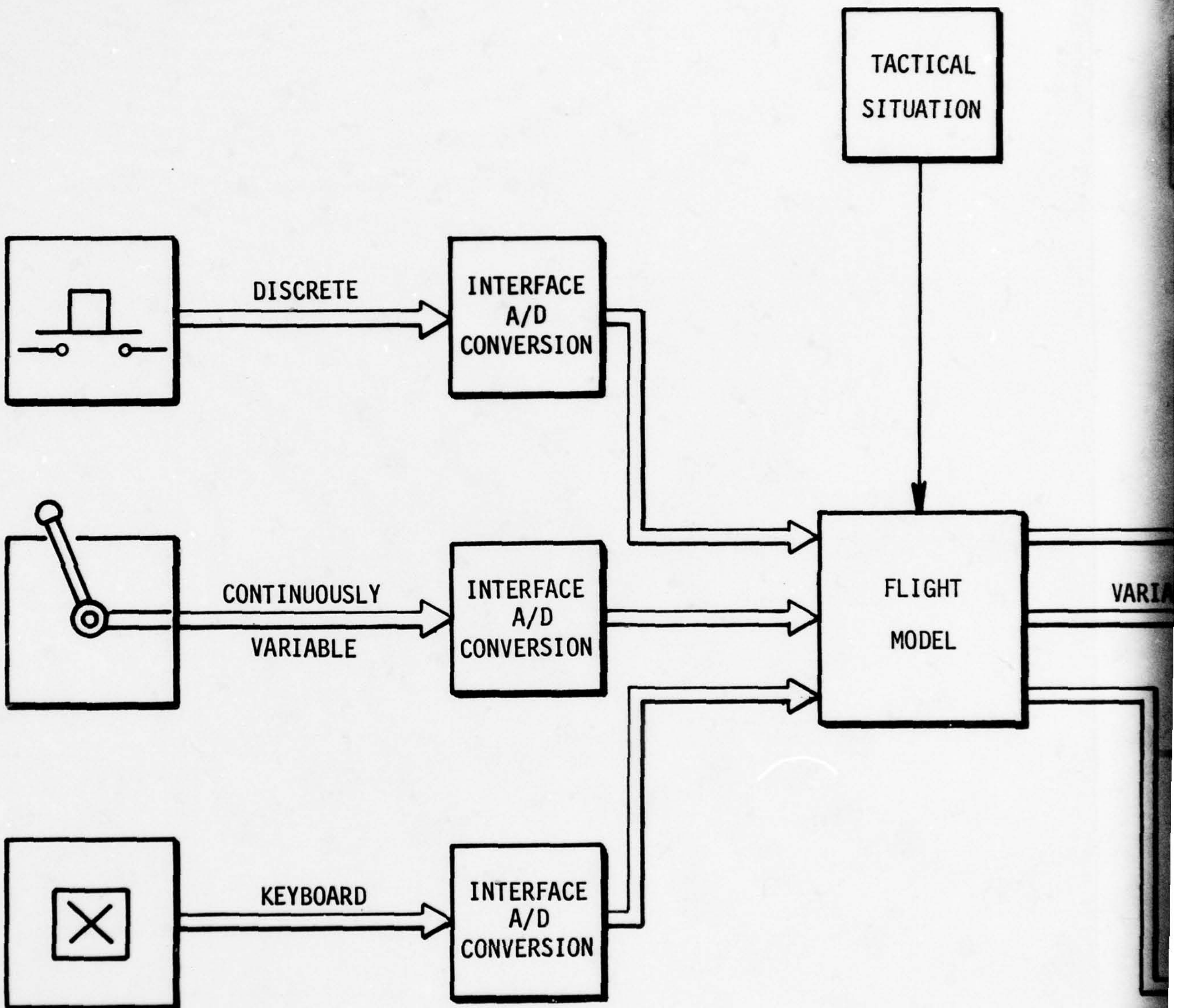
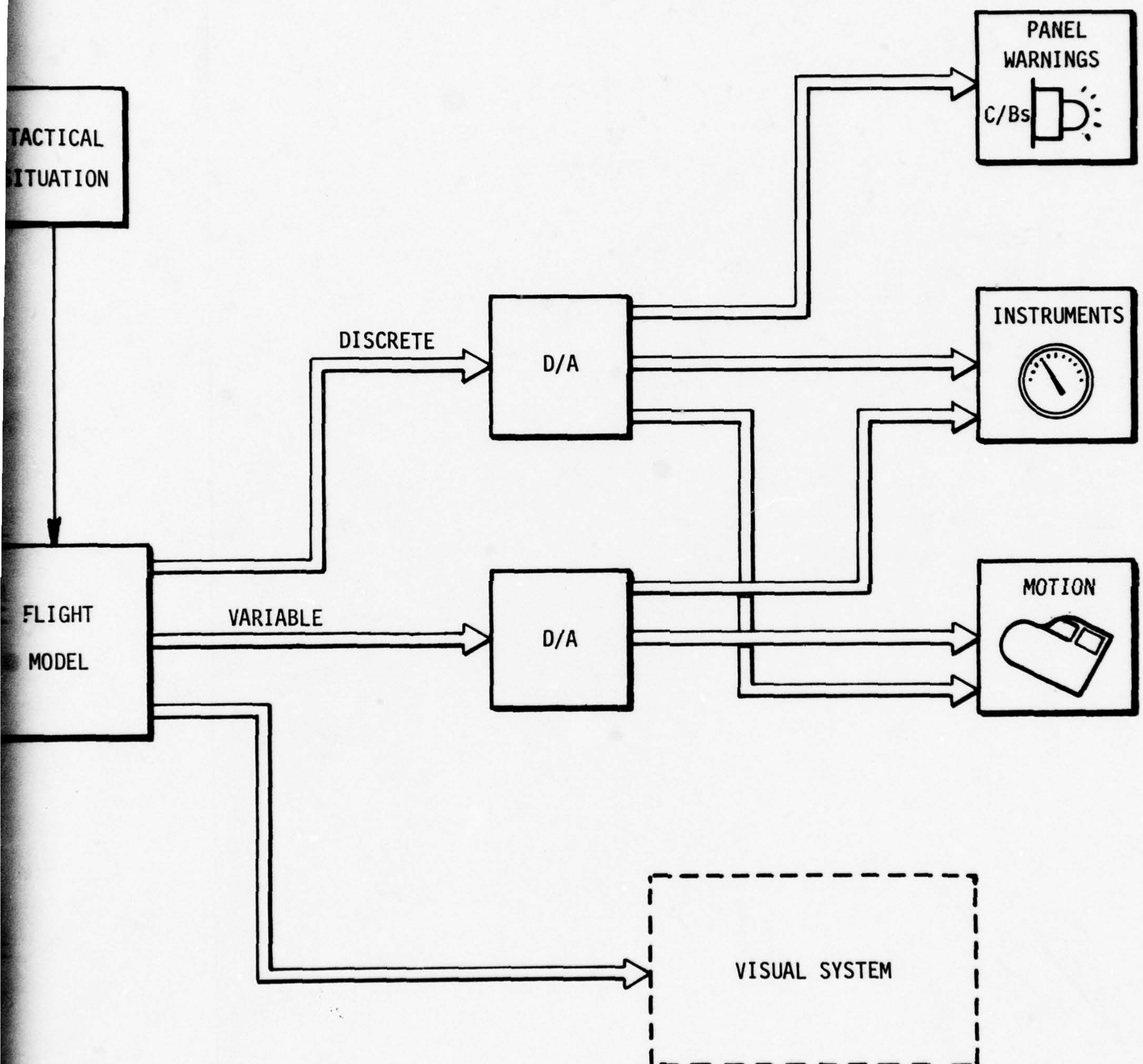


Figure 3-2. Flight Model - Major Input/Output Relationships



TACTICAL
SITUATION
PANEL
WARNINGS
C/Bs
DISCRETE
D/A
INSTRUMENTS
FLIGHT
MODEL
VARIABLE
D/A
MOTION
VISUAL SYSTEM

2

3.5.2.1.1 Crew Inputs. Crew inputs must operate in real time or with minimum delay. All crew inputs fall into the categories of continuously variable and discrete inputs, and must pass through the analog-to-digital conversion process in the computer interface. It is part of the software management responsibility to ensure that the transport delay is kept to a minimum, and the hardware design must ensure accurate and smooth processing of the variable signals.

3.5.2.1.1.1 Flying Controls. The flying controls consist of the cyclic stick with both fore-aft and lateral positions, the collective stick and the rudder pedals, one set for each crew member. The simulation of the control feel system is described in paragraph 3-3. The flight model therefore requires control position information, which is used in conjunction with hydraulic power, Backup Control Systems (BUCS) and Automatic Stabilization Equipment (ASE) information to calculate the following:

- The main rotor blade cyclic and collective pitch angles
- The tail rotor collective pitch angle
- The wing flap angle

The response characteristics of the hydraulic actuators should be included in the rotor blade pitch angle calculations. Data should be readily available for the geometrical relationship between crew control and blade or control surface angle, and also for the hydraulic actuator frequency response.

3.5.2.1.1.2 Engine Controls. The only variable engine control is the power lever. Four power levers are provided in the aircraft, one for each of the two engines for each crew member. The lever position will be used to position the engine operating speed and thus derive the power output to the rotor as described in paragraph 3.7.2.

3.5.2.1.1.3 Crew Discrete Inputs. Examples of crew discrete inputs which directly affect the flight model are ASE, BUCS as well as engine and fuel control switches.

3.5.2.1.2 Instructor Inputs. The instructor has the capability of affecting the flight model with inputs which generally do not require instantaneous transmission to the model. Examples of the instructor's influence are:

- The adjustment of:
    - the aircraft's weight
    - the center of gravity
    - stores
- Atmospheric changes such as:
    - temperature
    - wind and turbulence levels
- Insertion of malfunctions which affect the flight controls or aerodynamics. These effects are entered through the instructor facilities as mentioned in Section 7.

In an independent crew training configuration it would be desirable to provide the copilot/gunner instructor with the capability to control the aircraft. This would necessitate a set of variable controls operating in real time.

3.5.2.1.3 Tactical Situation Inputs. This category includes those forces which are applied to the aircraft flight model due to the firing of an armament, jettison of external stores, and enemy impacts, as applicable. Reaction forces can be expected when firing the area weapons cannon, a missile or some folding fin rockets, or in the event of a "hang-up". No serious time delays are expected as all of these effects should be computed within the tactical situation software. The exact forces are dependent upon gun recoil characteristics, rocket thrust build-up and the release or jettison sequence. All this data should be readily available. The tilt angle of the wing stores is controlled by the fire control computer. This angle obviously affects the aerodynamic characteristics of the helicopter so these effects must be included in the flight equations.

3.5.2.2 Output Parameters. Outputs from the flight model are processed by the input/output (I/O) handler and are passed through digital-to-analog converters to provide crew cueing data through panel warning lights, aircraft instruments, visual scene orientation and motion acceleration cues. The aircraft latitude and longitude can also be computed.

Both discrete and variable command signals are processed through I/O channels. It is very important, to ensure an effective training device, that the transport delays of the command signals to the instrument. visual and motion hardware are kept to a minimum. Gum and Albery (Ref. 3-4) describe the consequences of poor design in this area. The solution lies in careful software management of data transfer from CPU to CPU, and between CPU and hardware. The relevant equations of flight dynamics, the instruments, the visual and the motion systems should all be executed at the same time interval with the flight dynamics executed first in the sequence.

3.5.2.3 Flight Model Modules. Each module of the total flight dynamic model is described herein. A layout of the main modules of the flight dynamic model is shown in Figure 3-3. The order of execution of the modules is important for numerical stability and model dynamic response. The modules are referred to herein in the basic calculation sequence required.

3.5.2.3.1 Automatic Stabilization Equipment (ASE). This consists of a two channel 3-axis electrohydraulic feedback system. Pitch, roll and yaw gyros measure aircraft angular velocity and an accelerometer measures lateral acceleration. These signals are processed and filtered by the ASE computer to provide an additional series of inputs to the hydraulic control actuators at the main and tail rotors. The total blade angle is the sum of the pilot's control (stick) input and the ASE input, suitably filtered by the control actuator transfer function. The gain and transfer function data will be required for the simulation of the ASE computer and such information should be readily available.

Provision is necessary for system malfunctions such as loss of signal or signal runaways. The system will only be functional provided suitable electrical and hydraulic power is available to the system components.

3.5.2.3.2 Main Rotor Forces. The main rotor force and moment equations are fundamentally the most important part of the flight dynamic equations. The most efficient technique for the rotor equations is to employ a modified

Ref. 3-4. Gum, D. and Albery, W., Integration of an Advanced GIC Visual and Simulator System, Proceedings of the AIAA Visual and Motion Simulation Conference, Dayton, 1976.

linear strip theory approach. The basic theory (e.g. Gessow and Myers (Ref. 3-5) utilizes the calculation of blade section lift and drag and integrates these quantities algebraically over the span and the azimuth. By this means the total forces and moments are calculated from algebraic equations containing typically the following terms as shown in Equations (3-1) and (3-2):

$$\text{Force } F = f(R,\ b,\ c,\ \Omega,\ a,\ C_F) \tag{3-1}$$

where
- R = rotor radius
- b = aerofoil span
- c = aerofoil root chord
- Ω = rotor angular velocity
- a = aerofoil lift curve slope
- C_F = force coefficient

The force coefficient C_F is a non-dimensional parameter dependent on an equivalent blade angle of attack and calculated as follows:

$$\text{Force Coefficient } C_F = f(\Theta_0,\ B_1,\ A_1,\ \mu,\ \lambda,\ a_{1s},\ b_{1s},\ a_0) \tag{3-2}$$

where
- Θ_0 = Collective Pitch Angle
- B_1 = Fore-Aft Cyclic Pitch
- A_1 = Lateral Cyclic Pitch
- μ = tip speed ratio
- λ = inflow ratio
- a_{1s} = fore-aft flapping angle
- b_{1s} = lateral flapping angle
- a_0 = coning angle

These forces and moments would be calculated in rotor axes X_R, Y_R and Z_R where the origin is at the rotor hub and the Z_R axis is along the shaft. Therefore, all velocities and other terms used in the force and moment equations must be in rotor axis coordinates. The rotor axis system differs from the fixed body axis system X, Y, Z (Figure 3-4) in which the origin is at the center of gravity and the Z axis is perpendicular to the fuselage reference line. A knowledge of the blade first harmonic flapping angles is required for the force and moment equations. These angles are obtained using a similar technique involving the summation of moments about the flapping hinge. The general flapping angle is defined in Equation (3-3)

Ref. 3-5. Gessow, A. and Myers, G., Aerodynamics of the Helicopter, F. Ungar Publishing Co., New York, 1967.

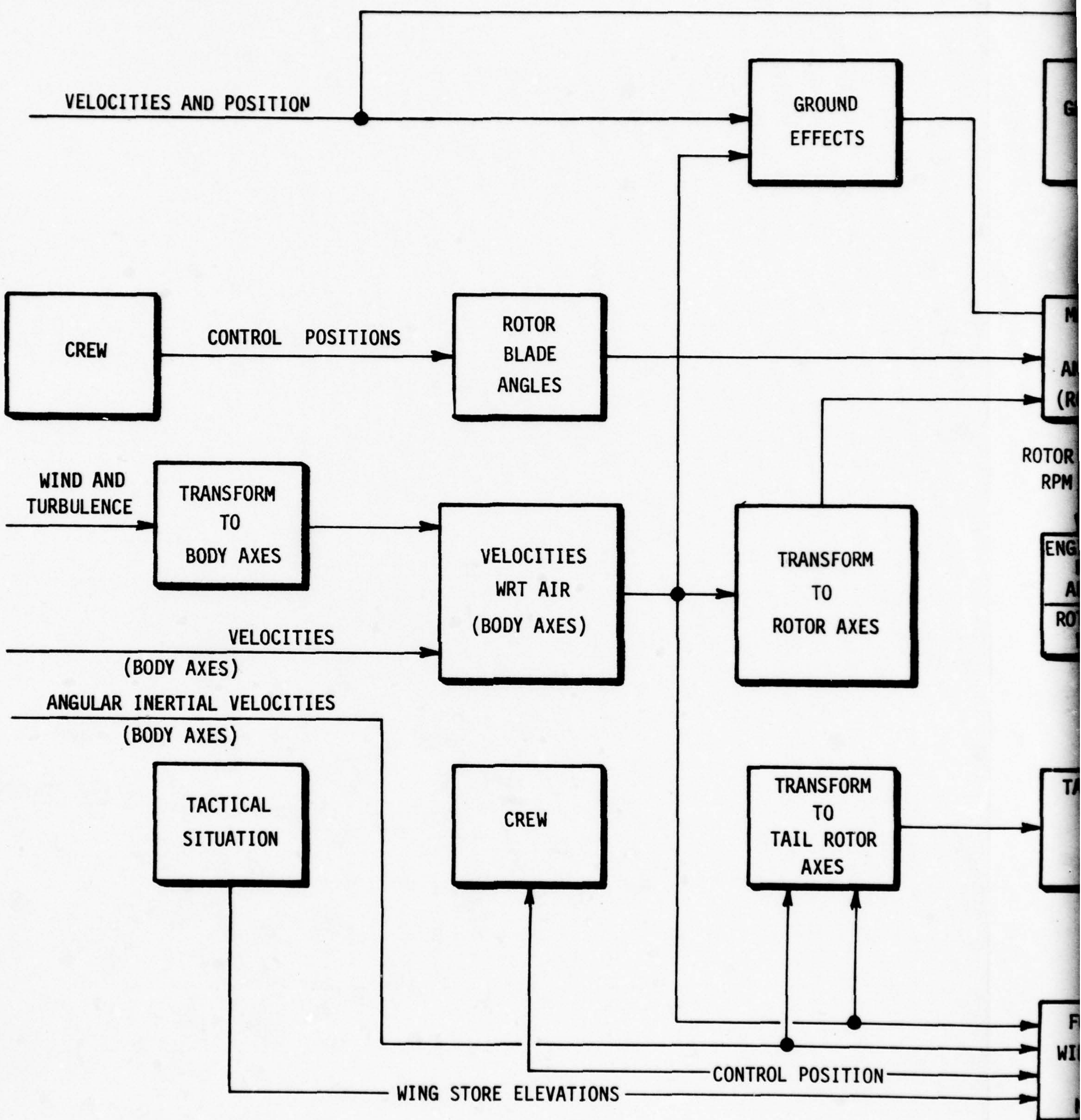
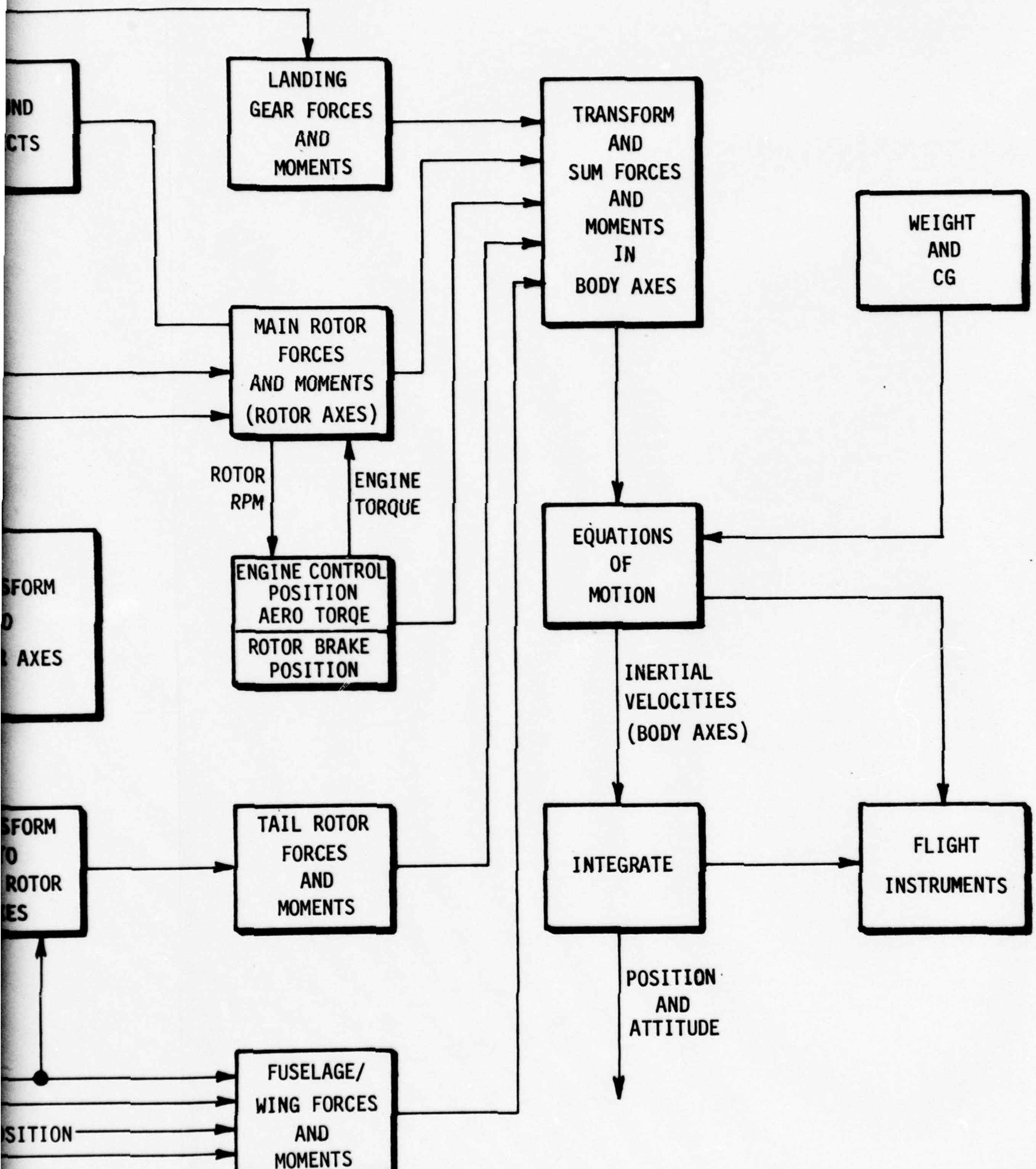
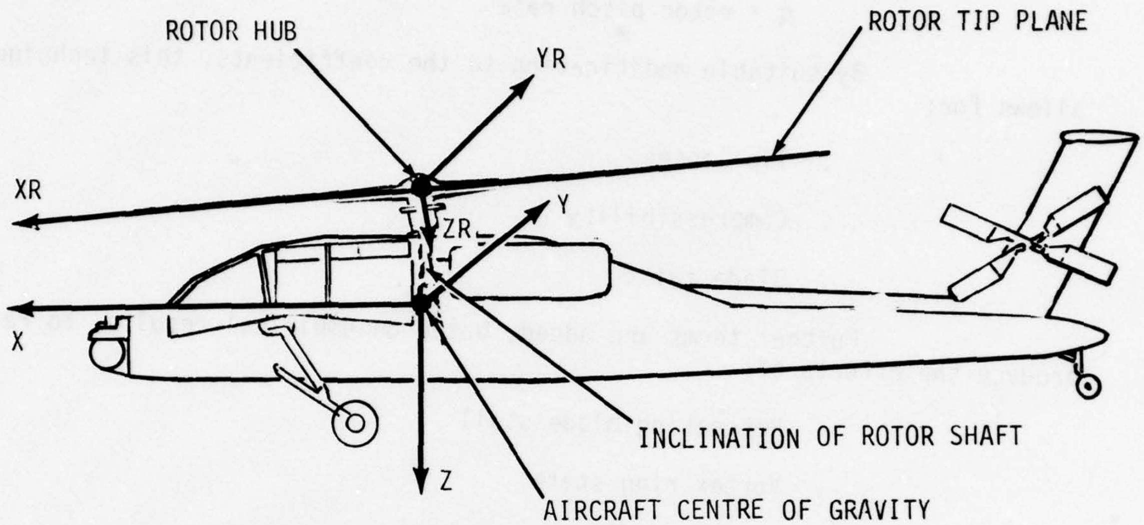


Figure 3-3. Flight Dynamics Block Diagram



IND
CTS
LANDING GEAR FORCES AND MOMENTS
TRANSFORM AND SUM FORCES AND MOMENTS IN BODY AXES
WEIGHT AND CG
MAIN ROTOR FORCES AND MOMENTS (ROTOR AXES)
ROTOR RPM
ENGINE TORQUE
ENGINE CONTROL POSITION AERO TORQE
ROTOR BRAKE POSITION
SFORM
D
AXES
EQUATIONS OF MOTION
INERTIAL VELOCITIES (BODY AXES)
SFORM
O
ROTOR
ES
TAIL ROTOR FORCES AND MOMENTS
INTEGRATE
FLIGHT INSTRUMENTS
POSITION AND ATTITUDE
FUSELAGE/ WING FORCES AND MOMENTS
SITION

2



X, Y, Z = AIRCRAFT BODY AXIS SYSTEM

XR, YR, ZR = ROTOR AXIS SYSTEM

Figure 3-4. Helicopter Rotor and Body Axes Systems

$$\beta = a_0 - als \cos\psi - bls \sin\psi \tag{3-3}$$
$$= f(\theta_0, A_1, B_1, p, q, \mu, \lambda, \psi) \text{ in the steady state}$$

where β = flapping angle
ψ = blade azimuth angle
p = rotor roll rate
q = rotor pitch rate

By suitable modification to the coefficients, this technique allows for:

. Tip losses

. Compressibility

. Blade twist

Further terms are added, based on empirical results, to reproduce the effects of:

. Retreating blade stall

. Vortex ring state

. Ground effect

The main rotor of the AH-64 is a fully articulated four bladed rotor with constant chord. This is largely a conventional configuration but one significant difference is the 20° sweep of the aerofoil at the outboard 7% span. This latter effect can be included in the force and moment equations by calculating extra terms using the same strip theory technique. The main rotor angular velocity is calculated in the engine simulation modules and derived from the torque balance equation.

In view of the large maneuvering envelope of this helicopter, the training value of this simulator may be enhanced by reproducing rotor stalling and vortex ring effects more accurately than is normally expected. Therefore, it will be necessary to obtain accurate flight data of these phenomena to establish their boundaries and their intensities. The rotor equations as presented above should be adequate in the low speed flight regime in any direction, and in ground effect, with the possible exception of the interference effects from other parts of the helicopter, such as tail rotor, fuselage, wings, etc. Such effects would probably be very dependent on the direction of flight. Again accurate flight measured data would be necessary to simulate these phenomena. It could be expected that such effects would produce an adjustment to the control positions for trimmed flight.

The flight envelope of the aircraft shows a minimum aerodynamic flight envelope of zero 'g'. This could indicate a negative main rotor thrust requirement, depending on the lift contribution of the fuselage and wings. The rotor equations are expected to accurately calculate thrust levels around zero and slightly negative.

The aircraft response requirements to a control displacement are described in Ref. 3-1. The lateral requirements of 13 degrees per second per inch are given in paragraph 10.3.5.2.1 of Ref. 3-1. Appendix C shows an example calculation for the estimated roll response of the CH-53 helicopter. This shows an achieved roll rate of 10 degrees per second per inch with the AFCS disengages. The similarity of these figures indicates that the basic dynamics of the rotor system of these two aircraft are not vastly different and the simulation experience of one aircraft can be carried over to the other. An accurate comparison can only be made when AH-64 data is available.

3.5.2.3.3 Tail Rotor Forces. The tail rotor design features two pairs of teetering blades mounted in elastomeric bearings, each pair arranged at 55 degrees in azimuth to the other. The blade pitch changes are through self-lubricating bearings with delta three coupling from flapping. The elastomeric bearings provide a semirigid flapping motion. The tail rotor forces which need to be calculated are thrust and torque. The thrust makes a contribution to the total yawing moment, rolling moment and sideforce. The torque makes a contribution to the torque balance equation of the engine and rotor system. Other forces and moments from the tail rotor are generally small enough to be neglected.

The thrust and torque can be calculated in a similar manner to the main rotor forces and moments. None of the novel design features (including 55 degrees blade azimuth and elastomeric bearings) is expected to preclude such an approach, providing mechanical and geometrical data is fully available. The equation for the thrust, for example, can be of the form as shown in Equations (3-4) and (3-5)

$$T_T = f(\Omega_T, a_T, b_T, c_T, R_T, C_{TT}) \qquad (3\text{-}4)$$

where the tail rotor parameters are Ω_T = angular velocity
a_T = lift curve slope
b_T = aerofoil span
c_T = aerofoil chord
R_T = rotor radius

and the thrust coefficient

$$C_{TT} = f(\Theta_{0T}, \mu_T, \lambda_T) \qquad (3\text{-}5)$$

where the tail rotor parameters are Θ_{0T} = blade collective pitch
μ_T = tip speed ratio
λ_T = inflow ratio

Any interference effects which occur from the main rotor and vertical stabilizer in low speed flight or ground effect will have to be carefully evaluated in flight.

3.5.2.3.4 Fuselage Forces. For the purpose of this description the fuselage also includes the wings, wing stores, fin and tailplane. It is recognized that for the detailed analysis of the forces in the computer software, it may be necessary to treat each item separately. The wings are capable of carrying stores at four underwing attachments. The stores can be selected from a choice of three, i.e., fuel, hellfire missile cluster, rocket cluster. For the latter two, the stores can be adjusted in elevation angle, relative to the fuselage, through 4.5 degrees up to 28 degrees down. This angle is controlled through the fire control computer. Full span wing flaps are fitted for maneuvering control, operated by electrohydraulic actuators from the crew flight controls. The fin supports the tail rotor and the tailplane. The tailplane is mounted on top of the fin and is symmetrical about the fuselage centerline. The tail rotor is mounted at approximately the centre of the fin.

It is anticipated that the basic force and moment data for fuselage items will be obtained from the wind tunnel tests. Forces and moments should be available in three axes and over a wide range of angles of attack and sideslip. In order to faithfully simulate low speed flight a range of $\pm 180^{0}$ of sideslip should be covered and also $\pm 180^{0}$ of angle of attack would be desirable.

Data must be available which covers any possible wing store combination, and the full range of wing store elevation angles. The effects of wing flap angles should also be included. In order to integrate the fuselage items force and moment contributions into the total helicopter simulation, it will be necessary to modify the fuselage effects due to main rotor and tail rotor downwash. It is essential that this information be provided in the data package, as such effects are unique to the helicopter type.

3.5.2.3.5 Landing Gear Forces. The helicopter has a landing gear consisting of two main wheels and one castoring tail wheel. The gear is nonretractable, and steering control is not provided. Hydraulic disc brakes are provided on each main wheel.

The landing gear simulation model must be capable of accurately modelling the vertical forces of each of the three gears, developed by the oleo dynamics, and the tire side and longitudinal forces resulting from ground contact. These linear forces will also produce pitching, rolling and yawing moments about the aircraft center of gravity. The simulation must be realistic on ground slopes up to 15 degrees, and on any suitable landing surface provided on the visual system terrain models or through computer generated imagery.

3.5.2.3.5.1 Vertical Forces. The vertical forces originate from the oleo spring damper characteristics, and from the tire deflection, resulting from the tire contact with the ground. It is necessary, therefore that the oleo data includes spring and damper force information. The forces thus calculated in the simulation will then be used in the equations of motion to produce the helicopter oleo tire system dynamics.

Aircraft oleo systems have generally a very short response time and high natural frequency, compared to aircraft aerodynamic time constants. Therefore, the oleo system is only capable of accurate solution at short computation time intervals (of the order of 5 to 10 milliseconds). However, it has been discovered that by:

. Increasing the minimum oleo spring rate

. Decreasing the maximum oleo spring rate

. Increasing the minimum oleo damping factor.

A satisfactory oleo response can be obtained using the same computation time intervals as for the aircraft aerodynamic model (of the order of 40 to 100 milliseconds). It is anticipated that the same approach can be taken for the AH-64 simulator, which will result in the same successful solution. The minimum computation time interval, therefore, will be dictated by the requirements of the aerodynamic model or the visual display. The resulting oleo model therefore, should give realistic response to touchdown rates within the aircraft specification level, and to one wheel landings on sloping or level ground.

3.5.2.3.5.2 Horizontal Forces. The landing gear horizontal forces are produced by the friction between tire and ground. The important factors are:

. Ground texture and consistency

. Tire pressure

. Vertical force between tire and ground

. Tire slip ratio and slip angle

The basic properties of horizontal forces are given in Ref. 3-6. The drag force and sideforce components will be computed for each of the three gears. The drag force (the gear X-force) is described in Equation (3-6).

Ref. 3-6. Smiley, R. and Horne, W., Mechanical Properties of Pneumatic Tires with Special Reference to Modern Aircraft Tires, NASA TR R-64, Langley, 1960.

$$X_G = f(\mu, R, F_b \qquad (3\text{-}6)$$

where μ = coefficient of friction
R = vertical reaction force
F_b = braking force
X_G = gear X force

The computation of vertical force, R, is described in paragraph 3.5.2.3.5.1. The coefficient of friction (μ) is dependent upon tire pressure and upon the properties of the ground surface. Coefficients of friction are well known and well simulated for concrete runway surfaces under dry, wet and icy conditions, etc. But it may be necessary for the AH-64 simulator to operate from many types of terrain, from deep snow to loose sand, in which case coefficients of friction and tire drag data should be made available. The slip ratio has a significant effect on the coefficient of friction on hard surfaces. This effect is readily simulated, including the effect of 'break-out' friction to and from stationary condition.

The braking force, F_b, is readily calculated from brake system data and cooling data. The slip ratio increases with applied braking force.

The gear sideforce is given in Equation (3-7).

$$Y_g = f(\mu, \delta_g, R) \qquad (3\text{-}7)$$

where Y_g = gear Y force
μ^g = coefficient of friction
R = vertical reaction force
δ_g = tire slip angle

The tire slip angle, δ_g, is the angle between the wheel longitudinal axis and the local direction of travel. The resulting sideforce is dependent upon the slip angle in combination with the vertical force and the friction coefficient.

The overall effect of the tire horizontal forces is to produce gear dependent longitudinal and lateral forces and pitching, rolling and yawing moments at the aircraft center of gravity. It is particularly important for realistic takeoff and landing simulation, that the gear forces and moments are accurately calculated for very low velocities in any direction. By achieving this the simulator becomes realistic on slope landing maneuvers, and in torque and lateral balance on takeoff and landing.

3.5.2.3.6 Weight and Center of Gravity. The weight and center of gravity module of the flight dynamics covers the calculation of moments and products of inertia in the fixed body axis system (Figure 3-4) as well as gross weight and center of gravity position. The output parameters are fundamental to the equations of motion.

The data provided must contain as a minimum all the above parameters for the basic empty weight of the aircraft. Calculations can then be performed to increment the inertia, weight and center of gravity due to the addition of crew, fuel, external stores and armament, etc. Most of the calculations can be performed at much longer iteration intervals than are required for the flight dynamic equations, except for the case where stores are releases. For the latter case an immediate aircraft response would be expected. This could be programmed by either continually computing the relevant parts of the program at the shortest time intervals or by branching to the program when required. The amount of initial fuel, stores and ammunition is controlled by the instructor prior to takeoff.

3.5.2.3.7 Equations of Motion. The equations of motion use the total force and moment summation in each of the three fixed body axes (Figure 3-3). By dividing by the aircraft mass, or the appropriate moment of inertia, the linear or angular accelerations are calculated. Numerical integration with respect to time of the accelerations then produces body axis inertial velocities. The air velocity is obtained in each axis by adding the body axis, wind and turbulence velocity components to the translational inertial velocities. The inertial body axis velocities must then be resolved through the aircraft Euler Angles of pitch, roll and yaw to obtain the earth referenced inertial velocities. By further integration with respect to time the aircraft position and attitude is obtained. These techniques are well known for aircraft simulation, and there is no reason to depart from this method for the AH-64.

3.5.2.3.7.1 Computation Time Interval. The accuracy of numerical integration is dependent upon the time interval between successive computations, and also upon the method of integration. For instance, for larger time intervals, accuracy of integration can be achieved by use of higher order integration methods using, for example, two, three, or four sets of preceding values.

The speed of response or delay time of the computation is, however, only dependent upon the time interval. As the speed of response has a high priority in aircraft simulation, it is necessary to reduce the computation time interval consistent with available computer speed of operation and memory size. Higher order integration methods do not then become necessary for accuracy. Rectangular integration will therefore be used for the solution of the equations of motion, as shown in Equation (3-8).

$$X_n = X_{n-1} + \Delta t \cdot \dot{X}_n \quad (3\text{-}8)$$

where Δt = computation time interval

$$\dot{X}_n = \frac{dxn}{dt}$$

X_n = a typical position variable at time n

The AH-64 has a conventional hinged main rotor system, which will result in response characteristics not radically different from other conventional helicopters (eg. UH-1D, CH-47 and CH-53). For the purposes of the flight dynamic model, therefore, it is considered that the iteration time interval should be in the range of 50 to 100 milliseconds. Experience has shown that it is beneficial to use the shorter 50 millisecond time interval to avoid noticeable picture 'stepping' with the wide angle visual system.

3.5.2.3.8 Flight Instruments. The flight instruments module extracts the relevant parameters from the main flight dynamics calculations, modifies them for instrument response and error characteristics, then feeds the outputs into the digital-to-analog interface for transmission to the crew and instructor flight instruments.

The instruments concerned will be:

- Electronic Attitude Director Indicator (EADI)
- Instantaneous Vertical Speed Indicator (IVSI)
- Barometric altitude
- Radar altitude
- Airspeed Indicator (ASI)
- Normal acceleration
- Outside air temperature
- Turn and slip indicator
- Standby Attitude Direction Indicator (ADI)

The EADI is presently under development for the AH-64 and is the only flight instrument with which CAE is not familiar. The flight parameters indicated from the AH-64 System Specification include:

. Pitch and roll attitude

. Ground speed below 25 knots

. Airspeed above 25 knots

. Vertical velocity

. Radar altitude

For the pressure system instruments (altimeter, ASI) it is important to include position error correction and the effects of icing when appropriate. The normal accelerometer must reproduce the acceleration at the sensor location in the aircraft. Instrument power must be a function of the appropriate power supply availability. Malfunctions must be included as required. There is not expected to be any fundamentally unusual requirements for the flight instrument simulation.

3.5.2.3.9 Atmosphere Model. The atmosphere program module consists of:

(a) Modelling the international standard atmosphere from ground level up to the aircraft maximum altitude. The parameters are atmospheric pressure, density and temperature.

(b) Modelling the effects of deviations from the standard figures. These would be controlled by the instructor.

(c) Modelling steady wind conditions, set by the instructor.

(d) Modelling turbulence effects in a self-generated random manner, the magnitude is set by the instructor.

(e) Modelling the effects of large ground objects on local wind and turbulence.

Item (a) herein follows normal techniques using nonlinear functions of pressure. The temperature variation is constant at 1.98°C per 1000 feet up to the stratosphere. Item (b) involves the instructor setting a sea level temperature of other than the standard of 15°C. The program adjusts atmospheric density, and the temperature change is reflected through the altitude. Item (c) requires the instructor to set the wind velocity and direction at ground level, and possibly the variation of both with altitude. The program transforms earth reference wind velocities into aircraft body axes.

3.5.2.3.9.1 Free Air Turbulence. A free air turbulence model (item (d) above) should be available in the flight program with the instructor only required to set the level. Such a model requires the generation of a signal equivalent to passing white noise through a low pass filter described in Equation (3-9).

$$G(s) = \frac{a}{s + a} \qquad a = 0.314 \tag{3-9}$$

To do this, a digital signal (random number sequence) representative of white noise is produced and then passed through a digital equivalent of G(s). If the white noise signal were to be sampled at intervals of T seconds, the resulting sampled signal would be a series of spikes of random amplitude, the amplitude being normally (Gaussian) distributed.

For our use, the white noise signal is a computer generated pseudo random sequence. This signal is summed and sampled over a number of N iterations. The sampled sequence is then processed by the programmed equivalent of the filter Equation (3-9) to allow for gradual transitions between generated turbulence values. In order to maximize efficiency, this sampling interval was determined to be no less than 12 iterations (assuming 50 millisecond iteration rate). It can be shown that this signal has the required Gaussian distribution representative of wind turbulence.

3.5.2.3.9.2 Wind and Turbulence in Ground Proximity. The problem of reproducing the effect of ground shapes and protuberances on the aircraft local wind and turbulence characteristics is quite a complex one. It is of some importance to the training value of the simulator due to the fundamental requirement of nap of the earth flying for the helicopter. The effect of wind gusts and direction changes blowing around building, trees, cliffs and ravines will obviously increase the difficulty of the piloting task. The effects must be realistic and the data available reliable to ensure valuable training. This data can only be decided upon when the exact ground contours of each terrain model are known. If simulator response is not a true reflection of the aircraft response it should be possible to adjust the wind profile to satisfy user requirements. The ground proximity problem of wind and turbulence is divided into two areas. The wind streamlines, velocities and turbulence are affected differently over each of the following terrain:

- Flat and sloping ground up to 45 degrees slope
- Ground with steep slopes, cliffs, buildings etc.

3.5.2.3.9.2.1 Streamlines and Turbulence over Gentle Ground Slopes. A technique has been adopted at CAE for simulating local wind effects over sloping ground. This is presently utilized in the CH-47C simulation for the Iranian Air Force over a visual model including desert and mountainous areas. The basic technique involves adjusting the wind shear profile with altitude as a function of local ground slope. A typical effect is illustrated in Figure 3-5. The ground slope is calculated from a knowledge of the ground contour matrix stored in the computer memory. The wind is assumed to flow parallel to the local ground contour, hence updrafts and downdrafts are experienced at the helicopter. A downwind turbulence effect is reproduced which is dependent upon:

. wind speed

. height above ground

. ground slope

. incidence angle of wind to maximum slope

The overall effect is to modify the wind velocity and direction and to increase the turbulence as appropriate in a realistic manner over sloping terrain.

3.5.2.3.9.2.2 Streamlines and Turbulence around Steep Slopes. Examples of topographical features which would fit into this category are:

. Buildings

. Towers

. Cliffs

. Ravines

. Trees

. Woods

. Bridges

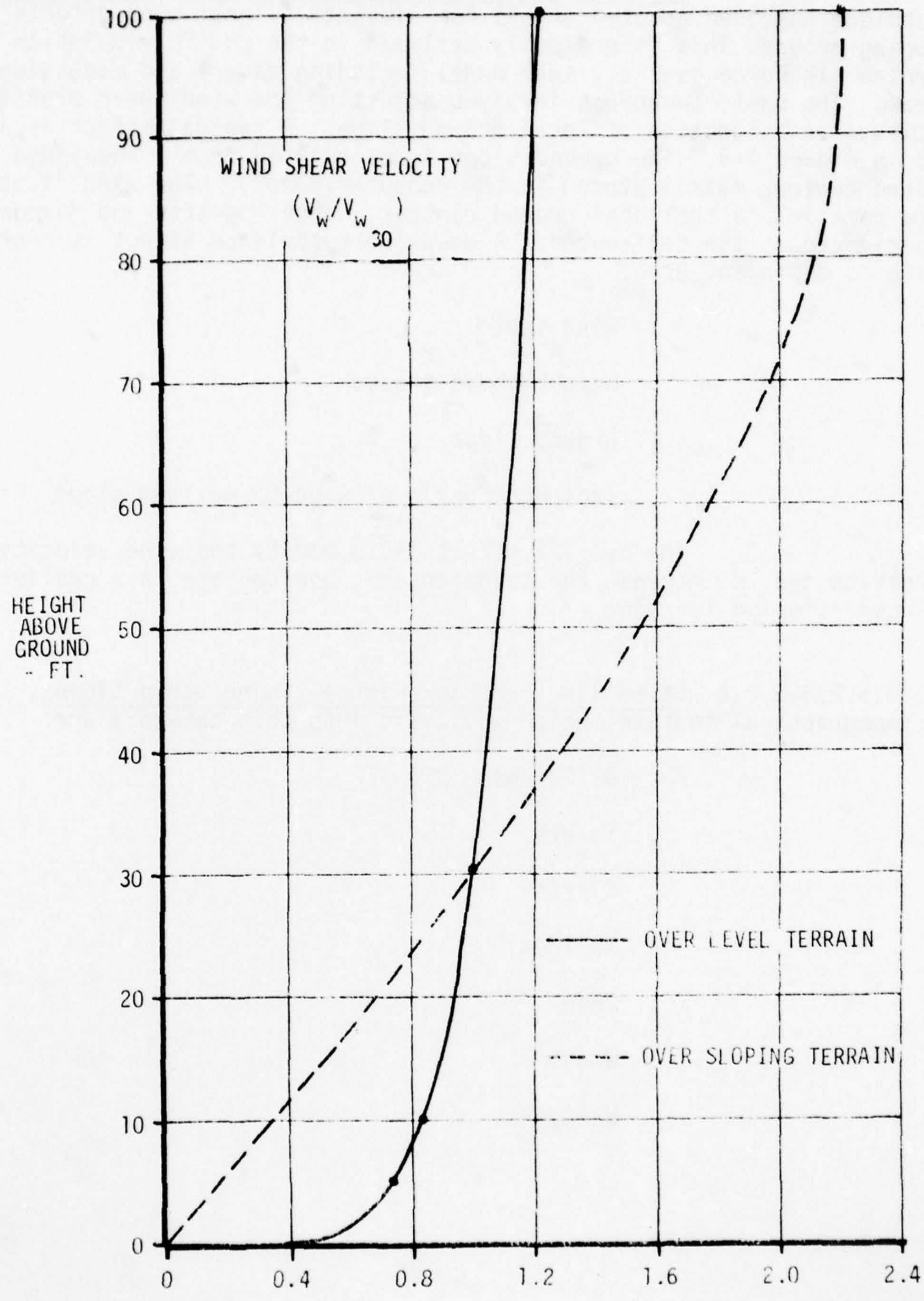


Figure 3-5 Wind Shear Profile Velocity

The effects of these features should not be ignored because the pilot will be expected to be in close proximity to these features during AH-64 tactical mission training. A first approximation for these features is to provide an area of reduced wind velocity on the lee side of the feature. A further refinement is to increase wind velocity around the top and edges of the object, and then add turbulence downwind of the edges and sides.

A basic review of early work on this subject, is given by Hoerner, (Ref. 3-7). It concentrates primarily on the effects of man made structures and buildings. For natural objects such as trees, woods and hills, which are more suitable for the AH-64 training scenario, an empirical approach must be taken. Trees and woods come into their own category which have a diffusive effect upon wind velocities and have no solid edges.

Accurate research work needs to be carried out on the effects of ground objects on local streamlines and velocity distributions. However in the absence of complete data it is considered that the present state-of-the-art allows some basic effects to be included in the wind and turbulence models for the AH-64 simulator.

3.5.2.3.9.2.3 Impact Upon Programming. The approach to be taken in programming these wind effects is described herein. It is assumed that the terrain model is available in the computer memory in matrix form, from which ground elevation and slope data is available.

(a) Measure the aircraft altitude and the ground slopes within one or two rotor diameters around the aircraft based on the terrain model matrix.

(b) If none of the slopes is more than 45 degrees, calculate the new local wind velocity and direction based upon the method in paragraph 3.5.2.3.9.2.1. The turbulence level is adjusted accordingly.

(c) If a slope does show more than 45 degrees, explore more adjacent matrix areas to determine the extent of the steep slope, and hence determine the proximity of the aircraft to the sides and top. Adjust the wind velocity and turbulence level based on the method in paragraph 3.5.2.3.9.2.2.

Ref. 3-7. Hoerner, S., Fluid Dynamic Drag, Published by the Author, 1965.

3.5.3 AH-64 Flight Model Summary. The basic flight dynamic modelling of the AH-64 helicopter will be a fairly straightforward task, in which CAE's previous experience of helicopter modelling will be of considerable advantage. It is assumed that basic data of the helicopter and relevant equipment will be available. This basic data includes all geometrical, mechanical and electrical measurements and calibrations.

It is necessary to obtain good consistent data in areas of potential weakness to ensure a successful simulator for pilot training. The potential weak areas are:

(a) The main rotor forces and moments should be reliable over the linear range of operation. Boundaries should be established by flight test of stalled and vortex ring flight regimes if this is considered an important area of training.

(b) The fuselage force and moment data must be applicable over a complete range of sideslip angles and angles of attack.

(c) The landing gear model requires ground surface friction and drag data for all surface conditions expected in simulator training.

(d) An accurate wind and turbulence model tailored to the terrain model topographic features will be a valuable asset to training. It must be acceptable to student pilots. CAE has a successful model for sloping ground already in use. The greatest area of uncertainty lies in the effects of bluff objects with steep slopes.

General programming features required of the flight dynamic modelling are:

(a) A computational time interval of 50 milliseconds.

(b) Some parts of the weight and center of gravity calculations (concerned with stores release) must be computed at the shortest time interval when required.

(c) Software modules must be managed so that there is a minimum time delay between execution of the flight dynamics and the transmission of the resulting data to the instruments, motion system and visual system.

3.6 NAVIGATION AND COMMUNICATIONS SYSTEMS

The navigation and communication systems onboard the AH-64 represent a standard package apart from the doppler navigation system still to be constructed. AH-64 navigation and communications equipment consists of the following items:

. Doppler navigation set AN/ASN-128

. VHF-FM communications and homing set AN/ARC-114

. Automatic direction finding set AN/ARN-89

. Heading attitude reference set AN/ASN-76

. VHF/FM communications and homing set AN/ARC-114

. VHF/FM communications radio set AN/ARC-115

. UHF communications radio set RT1167/ARC-164

. Communications Security Equipment TSEC/KY-28 for use with pilots radio set AN/ARC-114

. Transponder set AN/APX-100

. Intercommunications System

The methods of simulation proposed for the above systems are based on CAE experience in simulating similar helicopter equipment on the UH-ID, CH-53 and CH-47. However, since the AH-64 operates in a battlefield environment the navigation and communications equipment will show effects from module transmitters and enemy action which should be simulated. It is proposed to set up a flexible model under the instructor's control containing mobile radio stations, levels of jamming and noise.

3.6.1 Radio Station Data.

3.6.1.1 General. The requirements for ground based navigation stations and communication points in the AH-64 simulator are:

. Flexible on-line positioning of stations using manual or lesson plan placement by the instructor

. Realistic simulation of station signal strength through threat jamming

. Realistic simulation of station passage and cone of confusion

. Line of sight communication for VHF and UHF facilities only

At present the parameters used to define stations in CAE simulators are as shown in Table 3-1. The data is stored on disc. A disc capacity of 500 stations is currently being offered to a position of accuracy of ± 10 feet. CAE also provides a capability for loading the data on disc initially and a capability for making permanent modifications to the station data disc file, using background time and memory.

3.6.1.2 Type of Stations and Characteristics.

3.6.1.2.1 Simulated Landing Strips. Simulated landing strips may be used to train Ground Controlled Approach (GCA). Each landing strip equipped with GCA has letdown information including:

- The exact designation
- The latitude and longitude of the runway threshold
- The altitude of the runway
- The runway heading
- The magnetic variation
- The standard approach angle

The instructor can talk the helicopter down using instructor facility CRT pages displaying deviations from the approach path in numerical or graphical form. Such a facility would only normally be used in a nonbattlefield environment as operation in a high threat environment requires terrain flying to avoid enemy detection.

3.6.1.2.2 Nondirectional Beacons (NDB). NDB's provide signals which allow the automatic direction finder receiver (paragraph 3.6.2.4) to compute the bearing between the helicopter and the station. Parameters required by each station are:

- The exact designation
- Latitude and longitude of the transmitter
- The reception range
- The altitude of the transmitter
- The magnetic variation

TABLE 3-1. STATION PARAMETERS

	ITEM	PRE	COM	GCA	NDB
1	Index number	x	x	x	x
2	Identification	-	-	-	x
3	Frequency	-	x		x
4	Facility (Station Type)	x	x	x	x
5	Latitude (deg, min, sec, 0.1sec)	x	x	x	x
6	Longitude (deg, min, sec, 0.1sec)	x	x	x	x
7	Elevation (feet)	x	x	x	x
8	Magnetic variation (0.1^0 incr.)	x	x	x	x
9	Runway heading magnetic (0.1^0 incr.)	-	-	x	-
10	Glide slope angle (0.02^0 incr.)	-	-	x	-
11	Range: maximum	-	LOS		LOS
12	Runway roughness	-	-	x	-
13	Approach sector terrain profile	-	-	x	-

Symbols

x = applicable LOS = Line of Sight

\- = nonapplicable

- The station frequency
- The type of emission (AOA1 or AOA2)

No simulation development is required in this area, as NDB station characteristics are expected to conform to those already simulated by CAE.

3.6.1.2.3 Homing Stations. The battlefield environment in which the AH-64 simulator is primarily expected to train should include mobile homing devices. These devices will be expected to move as dictated by battlefield conditions and therefore FWS station data must be capable of being inserted by the instructor on-line.

Parameters required by each station are:

- The reception range
- The latitude and the longitude of the transmitter
- The altitude of the transmitter
- The VHF-FM frequency

Each of these parameters can be inserted through the instructor facility either by alphanumeric insertion on a page or use of CRT cursor to position the station on a map. Transmitter altitude shall be available from reference to the visual data base. Parameters which can be input during a training mission, distract the instructor from crew observation, or the parameters can be preset into a lesson plan and activated by the pushbutton during the mission. A capability for storing most of the parameters on disc is also being considered.

3.6.1.2.4 Friendly Mobile Stations. Radio transmissions from friendly vehicles is not seen as a problem for the AH-64. The approach to simulation is the same as for homing stations except the position and elevation of the transmitter must be continually updated automatically as the mission progresses. It is foreseen that most training missions will have preplanned tactical actions providing coordinates for moving vehicles.

3.6.1.3 Magnetic Variation. Magnetic variation is simulated in all present CAE helicopter simulators. The data is stored as a parameter of all fixed radio stations and in areas with few or no radio stations and large changes in local variation, dummy stations are specified. The variation at aircraft location is computed by interpolation between the nearest radio stations and represents the difference between true and magnetic heading.

3.6.1.4 Radio Station Signal Strength. The strength of signal received by the AH-64 equipment will be dependent on the following factors:

. Strength of transmitter output

. Distance between transmitter and receiver

. Terrain between transmitter and receiver

. Effect of enemy jamming on transmittion

The first two points can readily be calculated from the aircraft and transmitter positions and from station data entered by the instructor on the signal strength. The third point presents more of a problem as this requires knowledge of the terrain profile between transmitter and receiver. However a detailed map of the mission area will be covered by a visual data base used for line of sight calculations for radar warning and weapons detonation on impact. This data base will serve equally well for the purpose of line of sight calculations from radio transmitters. The final point is an area of which CAE has no data at present. For simulation purposes it is proposed to allow the instructor to insert a communications interference profile covering the frequencies to be affected. Variation of this profile should present the capability to represent threat jamming transmitters effectively.

3.6.2 Navigation Equipment.

3.6.2.1 General. The navigation equipment described in this paragraph will require full simulation in the AH-64. The simulation requirements are based on information contained in the Advanced Attack Helicopter System Specification (Ref. 3-1) and will be updated upon receipt of further data.

The following comments apply to the simulated navigation systems.

. Simplified standard antenna patterns should be employed for each type of radio station

. UHF and VHF communications signal strength should be computed as described in paragraph 3.6.1.4.

. Operation of simulation ground station transmitters or transponders should be under the control of the instructors facilities

. Only one station can be considered as being intune. Where two stations satisfy the intune condition at the same time, only the closer one is received.

3.6.2.2 Doppler Navigation Set AN/ASN-128. The navigation set installer on the AH-64 will be the doppler navigation set AN/ASN-128 which will permit a self-contained, low level navigation capability for flights during the hours of darkness and reduced visibility. The set provides the following for tactical operations:

Aircraft present position and target position in both Universal Transverse Mercator (UTM) and lat/long coordinates.

Digital signals that provide the following information:

- Magnetic bearing in degrees to preselected destinations relative to aircraft heading.
- Range in kilometers to preselected destinations.
- Sine and cosine of helicopter pitch, roll, and magnetic heading.
- Ground speed in kilometers/hour.
- Drift corrected steering data to selected destinations.
- Hover indicator drive.

A Computer Display Unt (CDU) will be installed in the copilot/-gunner station and an auxiliary navigation control panel will be installed in the pilot station.

The doppler will interface with other aircraft subsystems to accomplish the following:

TADS Target Prepointing. The doppler present position will be utilized by the FCC to calculate the line-of-sight from the aircraft to a previously stored target position (UTM coordinates).

Hover Display. Doppler hover velocity outputs will be digitally integrated by the FCC, appropriately compensated to include damping functions and then processed for display on the EADI and PNVS imagery.

Navigation Update. The TADS (laser rangefinder, turret LOS and a known landmark), will provide inputs processed by the FCC, which will update the doppler present position.

Reinitialization Switches. Reinitialization switches will be provided for the pilot and copilot/gunner to allow reinitialization of the digital integrators.

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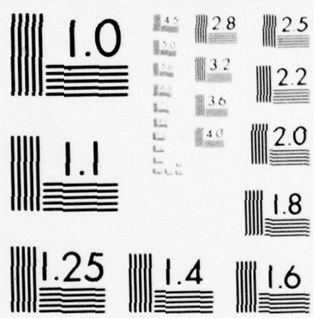

MICROCOPY RESOLUTION TEST CHART

<u>Growth</u>. Growth capacity and potential will be provided to allow the implementation of an automatic hover assist with the ASE Flight controls.

There are two feasible approaches to the smulation of the Doppler Navigation system (DNS). These are as follows:

(A) Install the CDU and provide the necessary inputs from software programs which simulate the receiver/transmitter antenna and the signal data converter units.

(B) Install the CDU front panel and simulate the CDU computer, the receiver/transmitter antenna and the signal data converter units.

The advantages of the method described in paragraph (A) are as follows:

(1) As the CDU may be in the development stage during the simulator design it may be difficult obtaining the detailed information required for faithful simulation of the CDU.

(2) Any changes in the CDU could be incorporated in the same manner as in the Helicopter CDU's, without necessitating changes in the simulator software.

(3) The simulator CDU would be interchangeable with the helicopter CDU's.

The limitations of the method described in paragraph (A) are as follows:

(1) System malfunctions will be limited to power and input/output failures.

(2) It will not be possible to carry out unrealistic helicopter procedures e.g. reposition.

The advantages of the method described in paragraph (B) are as follows:

(1) There will be a higher reliability in the system as there is less hardware which can fail.

(2) The system will be more flexible, allowing unrealistic procedures (e.g. reposition) to be accomplished and allowing a more comprehensive list of malfunctions to be incorporated.

The disadvantages of the method described in paragraph (B) are as follows:

- . The non-recurring cost of producing a simulation program for the CDU software will be high.

- . Simulation of the CDU program will use considerable computer time and memory.

At present there is insufficient data to make a decision as to the best method to simulate the DNS. It would appear that the method discussed in paragraph (A) would be preferable providing a means to reposition the aircraft were available. The Hughes Helicopters System Specification for the Advanced Attack Helicopter (Ref. 3-1) states that the TADS shall provide inputs, processed by the FCC which shall update the doppler present position. The Military Specification for the Doppler Navigation Set AN/ASN-128 (Ref. 3-8) makes no mention of a means (or an input) via which this could be accomplished. If there is an external facility for updating present position, it may be possible to reposition the helicopter. Alternatively, it may be possible to modify the CDU to allow reposition.

3.6.2.3 VHF-FM Homing. A complete simulation for the FM homing AN/ARC 114 over its operating range of 30 to 75.95 MHz is proposed. The steering information produced from the FM homing signal should be presented on the simulator Electonic Attitude Direction Indicator (EADI) through a special interface channel. The signal strength must also be displayed on the EADI as a pointer display moving vertically upward to indicate station approach.

3.6.2.4 Automatic Direction Finder (ADF). The AH-64 will be installed with direction finder set AN/ARN-89 which will display bearing signal information on the pilot Horizontal Situation Indicator (HSI) and the copilot/-gunner Radio Magnetic Indicator (RMI).

Bearing calculation and the characteristics of station fly over are within the capabilities of present CAE simulation and should not require any simulation development. Range and bearing to the station are calculated using spherical trigonometry, disregarding the ellipticity of the earth. Offtune conditions, long range conditions and station power are all taken into account in selecting the station being received and its signal quality. Beat frequency oscillator operation is simulated as applicable and receiver voice and static is set by the instructor.

Ref. 3-8. Navigation Set Doppler AN/ASN-128 (XE-2), MIL-N-49098 (EL), 29 July 1976.

3.6.2.5 Heading Attitude Reference Set (HARS). The AN/ASN-76 modified HARS will be installed on the AH-64 and will supply magnetic heading signal information to the compass card of the pilot HSI and the compass card of the copilot/gunner RMI. The simulation of the HARS should present no problems as it is similar to currently simulated equipment. When operated in the store mode, the magnetic heading of the helicopter is computed from magnetic deviation data interpolated from values stored for ground stations (refer to paragraph 3.6.1.3). In the free gyro mode the compass card reflects the correct operation of the free gyro system.

3.6.3 Communications Systems. Response to the communications in the AH-64 can be from the instructor or may be from a voice recorder. The use of a voice recorder to feed messages into the communications channels is usually applicable to commercial flight simulators for ATC weather messages. However, the battlefield environment in which the AH-64 will operate is likely to contain a number of voices on one channel. This clutter could be caused by requests made for remote Hellfire launches or targets handed off by scout helicopters. Timing of background messages can be controlled by the instructor through a lesson plan step or by mission events e.g. on reaching a rendevous point if the correct channel is selected.

The inclusion of voice recordings on the communications channels incurs no extra expense as a recorder is a prerequisite of maneuver demonstration.

Operation of the security voice equipment and the transponder set would be for operational checks only on board the simulator. The expected lights should illuminate on the panels but no message scrambling would be produced on the communications channels as this can serve no practical purpose. The intercommunications system and switches are required to have the correct effect in the FWS as the Intercom is the primary method of communication between the two crew members. Existing CAE simulators and simulator complexes already have this feature.

3.7 PROPULSION AND ANCILLARY SYSTEMS

3.7.1 General. Propulsion and Ancillary System simulation includes the following areas:

- Propulsion System
- Transmission System
- Electrical System
- Hydraulic System

- Auxilliary Power Unit (APU)
- Fuel System
- Brake System
- Fire Protection System
- Pressured Air System

When considering the application of these systems to the AH-64 FWS, it seems reasonable to assume that existing simulation design can be applied without too much modification. The design techniques itemized in the following chapters should satisfy all Propulsion and Ancillary System simulation requirements for the FWS.

3.7.2 <u>Propulsion and Transmission System.</u>

3.7.2.1 <u>General</u>. The AH-64 is equipped with two horizontally-mounted T700-GE-700 turboshaft engines with a maximum power output of 1400 shp each. The engine power settings are controlled through the engine power levers which can be set in four discrete positions: OFF, IDLE, FLY and LOCKOUT which correspond to the shut-off, ground idle, intermediate, and electrical control unit lockout power lever spindle positions. The power management system automatically maintains power turbine speed (NP) and provides automatic engine load (torque) equalization with manual override to permit individual engine control. Engine start cranking is provided by a pneumatic starter fed by compressed air from the APU or from another engine.

The engine is twin spool with a gas turbine and power turbine. The power turbine is connected to the main gearbox which in turn drives the main rotor. The main gearbox also has output shafts to the tail rotor drive, and a rotor brake drive, and receives one input shaft from the APU as well as from the engine gearboxes. The accessory drives, (2 ac generators, 2 hydraulic pumps and an air compressor) are driven by the main transmission or the APU depending on the shaft speed delivered by both systems.

3.7.2.2 <u>Propulsion and Transmission Simulation</u>. CAE has already designed and installed twin engine propulsion and transmission simulations in CH-53 and CH-47 simulators and a similar model is envisaged for the AH-64.

The model is a dynamic simulation of the aircraft power plant rather than a direct translation to power output. This means that all transient effects present in the aircraft, e.g., the effect of sudden aerodynamic loads on the rotor speed are inherent in the simulation model. Also, the effects of engine mismanagement are automatically reproduced, e.g. a hot start if failure to motor over after a failed start.

The accuracy of the model is to a large extent dependent on the engine data available. In the event of poor data it is possible to incorporate the standard CAE model and fill in constants from user flight tests. The same applies to transmission system inertias and losses not normally supplied.

Inputs to the propulsion and transmission system modules are:

- Engine power lever angles
- Collective stick position
- Fuel availability from fuel system simulation
- Start and test switch positions
- Main rotor and tail rotor aerodynamic torque from the flight model.
- Malfunctions from instructor facilities.

These inputs are processed by the engine and transmission modules to produce:

- Net torque to rotor
- Main rotor speed
- Gas generator speed (NG)
- Power turbine speed (NP)
- Power Turbine Inlet Temperature (PTIT)
- Fuel consumption
- Engine and transmission oil temperatures and pressures
- Malfunction effects e.g. compressor stall.

Modules used to produce the outputs are as follows:

- . Fuel control unit
- . Gas generator speed integration
- . Engine torque calculation
- . Main rotor torque summation and integration
- . PTIT, oil pressures and temperatures and air bleed effects on the engine.

The fuel control unit is the heart of a CAE gas turbine engine simulation. By computing the fuel flow to the engine it it possible to integrate N_G to a steady position dependent on atmospheric conditions, power lever angle, and the collective pitch lever position which produced a signal to compensate for load changes.

The driving force for the gas generator can be calculated from a torque summation including starter and drag torques. N_G is described in Equation (3-10).

$$\dot{N}_G = f(P_{ST}, P_{LA}, \Theta_{COLL}, T_{AMB}, V_{TAS}, P_{AMB}, N_G) \qquad (3\text{-}10)$$

where $\dot{N}_G$ = gas generator speed increment

P_{ST} = starter pressure

P_{LA} = power lever angle

Θ_{COLL} = collective lever angle

T_{AMB} = ambient temperature

V_{TAS} = true airspeed

P_{AMB} = ambient pressure

N_G = gas generator speed.

Engine torque is derived from the nondimensional shaft horse power output for each engine. The horse power is corrected for power turbine speed and then converted to torque for output to the nose gearbox. The sum of the two engine powers minus the engine noise gearbox and main gearbox losses is calculated as the total torque to the rotor system. The rotor speed is calculated by the Equation (3-11).

$$\dot{N}_R = Q_{TOT} - Q_{AERO} - Q_{BRAKE} \qquad (3\text{-}11)$$

where $\dot{N}_R$ = rotor speed

Q_{TOT} = total engine torque output

Q_{AERO} = Aerodynamic drag (from flight system)

Q_{BRAKE} = rotor brake torque

After calculation of the main engine parameters it is a simple task to develop the PTIT through use of manufacturer data and all engine and gearbox oil pressures and temperatures from the relevant gearbox speeds.

3.7.2.3 Propulsion System Iteration Rates. The iteration rate of the engine program must copy the rate of calculation in the flight system of the aerodynamic load torque on the main and tail rotors to prevent engine oscillations. This rate need only apply, however, to these parts of the calculation involved with the engine torque development and with the rotor speed. It is possible to calculate all other parameters at a slower rate.

The fast rates used in the past have been either 50 or 100 milliseconds and no change of these rates is considered to be necessary for the AAH.

3.7.3 Ancillary Systems. The ancillary systems onboard the AH-64 are of a standard type found on most military helicopters with the possible exception of the APU and pneumatic systems. Generally APU are found on larger cargo type helicopters and engine starters tend to be hydraulic rather than pneumatic. It is not anticipated that any problems will arise in the simulation of ancillary systems as similar simulations of CH-47 and CH-53 helicopters have already been integrated in CAE simulators.

3.7.3.1 Electrical System. The AH-64 electrical system is powered from two 30 kVa, 115/200 volt, 3-phase, 400 Hz ac generators driven from the main transmission accessory pads and from a nickel cadmium, 13 ampere hour, one hour rate 24 Vdc battery. The generators feed two ac essential busses during normal operation and in the event of a generator failure both systems are driven from one generator. Two 165 amp, 28 Vdc transformer/rectifiers are fed from the ac busses to supply power to two dc essential busses. The dc essential busses also cross-tie in the event of a transformer/rectifier failure. The emergency bus is normally supplied from the DC essential busses but during emergency operation will be battery powered. During normal operation the battery is recharged through the battery charger.

Simulation of the electrical system involves the calculation of all frequencies and voltages produced by the generators, transformer/rectifiers and battery which are adjusted to reflect aircraft loads. Faithful simulation of the Generator Control Units (GCU) including all applicable relay status if necessary. From this it is possible to determine whether or not busses are powered. In recent CAE simulators it has been the policy to wire all circuit breakers as discrete inputs to the computer software, by using the bus state and the circuit breaker state to develop a software circuit breaker power state to be referred to by other systems. Such a system removes the need for aircraft wiring of circuit breakers and switching power onto simulator busses when bus power states change. The outputs

required of the electrical system are:

. Circuit breaker states

. Generator frequency and voltage

. Equipment loads

The simulation of the electrical system requires similar detail to that of a CH-47 and should require little system development.

3.7.3.2 Hydraulic System. The hydraulic system on the AH-64 consists of primary and utility subsystems.

. The primary system provides power to the cyclic, collective and directional controls

. The utility system provides power to the cyclic, collective and directional controls and for the flaps, the rotor brake, area weapon aiming drive, APU start, and external stores elevation mechanism.

APU start provision includes a hydraulic accumulator and a single action hand pump. The subsystems consist of transmission-driven pumps (4.1 GPM @ 3000 psi) and accumulators to supply oil pressure.

Simulation of the hydraulic system involves calculation of hydraulic flows derived from system demands. Accumulator pressure can then be calculated by integrating the system demand and the available fluid from the pumps which also gives hydraulic pump demand. This allows the pump output pressure to be calculated from the transmission speed, oil availability and the effect of oil flow demand on the pump characteristics. The effects of pressure levels calculated in the systems are then reflected in the control forces on the flight control and on the overall performance of the aircraft. This area of simulation has already been successfully integrated on many CAE simulators and has operated to customer satisfaction.

3.7.3.3 Auxiliary Power Unit (APU). The APU installed on the AH-64 is an Airesearch GTP36-55(C) gas turbine unit rated at 125 horsepower. The output shaft from the APU feeds into the main transmission system where it can drive the accessory pads for generator, hydraulic and pneumatic pump actuation.

The output parameters required of APU simulation are the APU gas generator speed and APU fuel consumption. By accurately programming the control system of the APU it is possible to derive the starter engagement, the speed demand signals and the fuel supply availability. Transient

simulation can then be implemented through acceleration curves to allow the APU to obtain its operating speed and load change factors to simulate sudden clutch engagement or generator and pump load increases. Such a simulation has been found acceptable for previous helicopters and should satisfy AH-64 requirements.

3.7.3.4 Fuel System. The AH-64 fuel system consists of a forward and an aft fuel cell in the fuselage and complete provisions for an extended range kit on the wing pads. The forward cell usable capacity is 151 gallons while the aft cell holds 218 gallons. Two way fuel transfer is provided by a manually controlled pneumatic powered pump. Manual valving is provided to allow crew members to select either cell to either engine or both engines to either one cell or the other. Fuel is supplied to the engines by engine mounted suction pumps which is supplemented by the use of a pneumatically operated fuel boost pump during starts and during ineffective suction pump operation.

Simulation of the fuel system is by calculation of the fuel demanded of each cell from engines, APU and fuel crossfeed operation. The fuel levels can then by decreased or increased during fuel transfer by integration of the fuel demand. The amount of fuel in each tank is monitored on instruments and reflected in the center of gravity calculation. This type of simulation which has been found acceptable on CAE simulators to date, should satisfy requirements.

3.7.3.5 Brake System. The braking system on the AH-64 consists of two hydraulic single floating disc multiple spot brakes attached to the main landing gear. Actuation of the brakes is through the pedals and the system also has a mechanically locking parking brake.

For simulation purposes the braking force is calculated as a function of the pressure on the pedals which is accepted by the flight system to calculate the overall direction effect on the helicopter. This is a simple system and should satisfy requirements.

3.7.3.6 Fire Protection System. The AH-64 fire protection systems include two detectors located in each engine nacelle and two detectors located in the APU compartment. Fire extinguishing equipment includes two 60 cubic inch fire bottles containing 1 1/2 pounds of bromotrifluoromethane (CF_3Br) which can be discharged into either engine or APU compartments as selected by the crew members.

Simulation of the fire protection system is of a purely digital nature including simulation of all relays, switches and lights of the control system to correctly simulate test and fire detection and extinguishing functions.

3.7.3.7 Pressurized Air Systems. The pressurized air system is provided for the following:

- Operation of the Environmental Control System (ECS)
- Engine starts
- Fuel boost pump
- Engine cooling louvers
- Pressurization of the hydraulic system reservoirs
- Hydraulic fluid heat exchanger cooling ejector and extended range fuel tanks

The system is supplied with compressed air from a manifold supplied with air from a Shaft Driven Compressor (SDC) mounted on an accessory pad. Standby compressed air is available from left engine bleed air in response to a drop in output from the SDC.

A simple simulation model is envisaged for this system, two pressure sources being calculated from the compressor shaft speed, the gas generator speed of the engine and the atmospheric pressure. If the engine bleed air is utilized, an airflow is required to feed back into the engine model for bleed effects on engine parameters.

SECTION 4

TACTICAL SYSTEMS MODULES

4.1 GENERAL

The systems discussed in this section are those peculiar to the role of the AH-64 in battlefield maneuvers. The operation of this equipment is intended to give the AH-64 an advantage in engaging, destroying and surviving enemy forces. The systems discussed are:

- Fire Control Computer (FCC)
- Aerial Rocket Subsystem (ARS)
- Point Target Subsystem (PTS)
- Area Weapon Subsystem (AWS)
- Target Acquisition Designation System (TADS)
- Integrated Helmet and Display Sight System (IHADSS)
- Radar Warning System (RWS)

The analyses presented on these systems suggest methods of simulating and incorporating tactical modules in the flight trainer. The recommendations contained herein are based on CAE's present knowledge of the systems involved.

4.2 FIRE CONTROL COMPUTER (FCC) (Ref. 4-1 and 4-2)

4.2.1 Introduction. The FCC contains a 16-bit, parallel, general purpose, micro-programmable processor; memory; power supply; and input/output electronics. The computer integrates the AH-64 fire control and target related operations associated with the delivery of all weapons carried by the AH-64. The computer performs the computations necessary for targeting navigation, weapon ballistic compensation, and supplies logic commands for controlling the fire control subsystem. The computer interfaces with the weapon subsystems, sighting subsystems, crew station controls and displays, laser rangefinder/designator, air data, attitude and velocity sensors.

Ref. 4-1. YAH-64 Advanced Attack Helicopter, Vol. 1, System Specification, RFP DAAJ01-76-R-0374, Hughes Helicopters, Culver City, Calif., 1976.

Ref 4-2. Critical Item Development Specification for the Fire Control Computer, AMC-DC-AAH-H3003A, Hughes Helicopters, Culver City, Calif., 1976.

The interface with these systems is either by a Multiplex Data Bus, in accordance with MIL-STD-1553A, or serial digital or standard digital, analog and synchro inputs and outputs.

The principal problem concerning the Fire Control Computer is whether the actual computer should be incorporated in the simulator or whether it should be emulated or simulated. A further problem is designing a nonstandard simulator interface for interfacing simulated systems to the Fire Control Computer or other subsystems that employ aircraft hardware.

4.2.2 Alternative Approaches for Simulation. For every simulator of a tactical vehicle that employs a complex weapon system computer an important decision has to be made. This is whether to incorporate the actual weapon system computer, to emulate it or to simulate the computer functions in the simulator computer. M. R. Ullah of Hughes Aircraft has written a paper (Ref.4-3) on approaches to incorporate weapon system computer functions in trainers. CAE believes from discussion with the Army that it is the policy of the U.S. Army to incorporate the actual weapon system computer in the simulator. The use of this approach has the advantage that changes to the operational software during simulator production and after acceptance can be introduced with minimum cost and delay and that the use of the operational software makes the performance of the simulator easy to evaluate. The disadvantages are that special simulator interface requirements have to be designed to interface the weapon system computer to the simulated subsystems. In addition certain capabilities of the simulator, such as store/recall, record/playback and maneuver demonstration, are not easily implemented from the outside of the weapon system computer. To solve this disadvantage, the weapon system computer operational software might have to be modified or limitations on the full simulator capabilities in the areas of store/recall, etc., for the tactical systems modules, may have to be accepted.

Emulation of the weapon system computer has the advantage that the operational software will be executed as if it were resident in the weapon system computer and will perform accordingly. Special instructions can be inserted to aid the implementation of simulator capabilities such as store/recall, etc. Disadvantages are that, if aircraft hardware is used for simulating other subsystems which interface with the weapon system computer, then special interface requirements may still have to be designed to interface to these subsystems. Also, if the weapon system computer is a state of the art device, then the development costs of the emulator may be large.

Ref.4-3. Ullah, M. R., Weapon System Computer Functions - Incorporation, Emulation, or Simulation, International Learning Technology and Exposition Proceedings, Vol. IV, Washington, 1976.

Simulation of the weapon system computer results in a certain saving in hardware costs although special interfaces to actual aircraft hardware subsystems may still be required as in the emulator's case, and allows simulator capabilities such as store/recall, etc., to be easily implemented. Disadvantages are that the simulator software has to be developed which imposes a time lag before the simulator can reflect changes to the weapon system operational software and that the fidelity of the simulation is always open to criticism particularly for complex weapon system functions.

With respect to the Fire Control Computer (FCC) employed in the AH-64, it is not as complex as a weapon system computer that would be found in a tactical strike aircraft but still has a significant processing capability. The computer interfaces with a number of aircraft panels and subsystems via the multiplex data bus. Some of these panels and subsystems in the simulator will use aircraft hardware. Therefore, there would still be a requirement to design special interface hardware even if the Fire Control Computer was emulated or simulated. It is expected that the simulator will be operational by the end of 1980 at which time the phase two engineering development of the AH-64 will be approaching its conclusion and hence the FCC software may still be under development with the consequent possibility of changes occurring.

In view of the above-mentioned points, CAE agrees with the policy of the Army to incorporate the actual fire control computer into the simulator as the best approach and has devised a preliminary fire control computer system configuration accordingly.

4.2.3 FCC System Design Analysis. The input/output capabilities of the FCC consists of discrete, analog and synchro interfaces, digital serial interfaces and the multiplex data bus interface. The discrete, analog and synchro interfaces are believed to be standard aircraft type interfaces and can be driven from the CAE Datapath Interface. The digital serial interface is more recent as regards its use on aircraft but is now finding increasing use in military aircraft. CAE has designed the necessary digital serial interface between a simulator computer and an aircraft weapon system computer for the European Tornado Simulator. The clock rates employed in the Tornado and the AH-64 may well be different but the interface hardware will be directly applicable.

The majority of the data transfers between the various avionic subsystems in the AH-64 are by a Multiplex Data Bus system in accordance with MIL-STD-1553A. None of the documents CAE has received identify a complete listing of which subsystems or portions of subsystems employ the data bus for their data communication. However, certain subsystems which use the data bus can be identified, such as the Fire Control Symbol Generator, Electronic Attitude Direction Indicator and the Hellfire Control Panels.

A partial system block diagram for the multiplex data bus system proposed for the simulator is shown in Figure 4-1. The philosophy behind this system approach is as follows:

(a) For those subsystems or portions of subsystems for which the actual hardware is used in the simulator, they would be connected to the data bus via their respective Remote Terminals (RT), which could be separate LRU's or modules within the actual equipment.

(b) For those subsystems or portions of subsystems that are simulated by software, a RT for each simulated system would be connected to the data bus, as in the AH-64, and also would be interfaced to the simulation computer.

MIL-STD-1553A specifies that each remote terminal has one fixed address and that it has data buffers to receive and transmit a maximum of 32 data words to and from the data bus. Therefore it appears necessary for each simulated subsystem to have its own dedicated RT interfaced to the simulation computer.

The data bus has the capability for data to be transferred from one subsystem to another without the data going through the FCC. The bus controller issues the appropriate transmit and receive commands to the two remote terminals and also appears to monitor that the data has been transferred and that appropriate status words have been transmitted. Therefore, when transmitting data between two simulated systems it is not sufficient to transfer the data via an internal computer cross-reference transfer. Instead, it appears that, when commanded by the bus controller, data must be transmitted out through one remote terminal and then will come back in to the simulator computer through another remote terminal so as to satisfy the monitoring software/hardware in the bus controller. This appears to be an unnecessary data transfer requirement for the simulator and the possibility of modifying the bus controller software to prevent transfers of data between simulated subsystems will be examined.

For details concerning the method of interfacing the simulation computer to a remote terminal, please refer to paragraph 8.3.6.3.

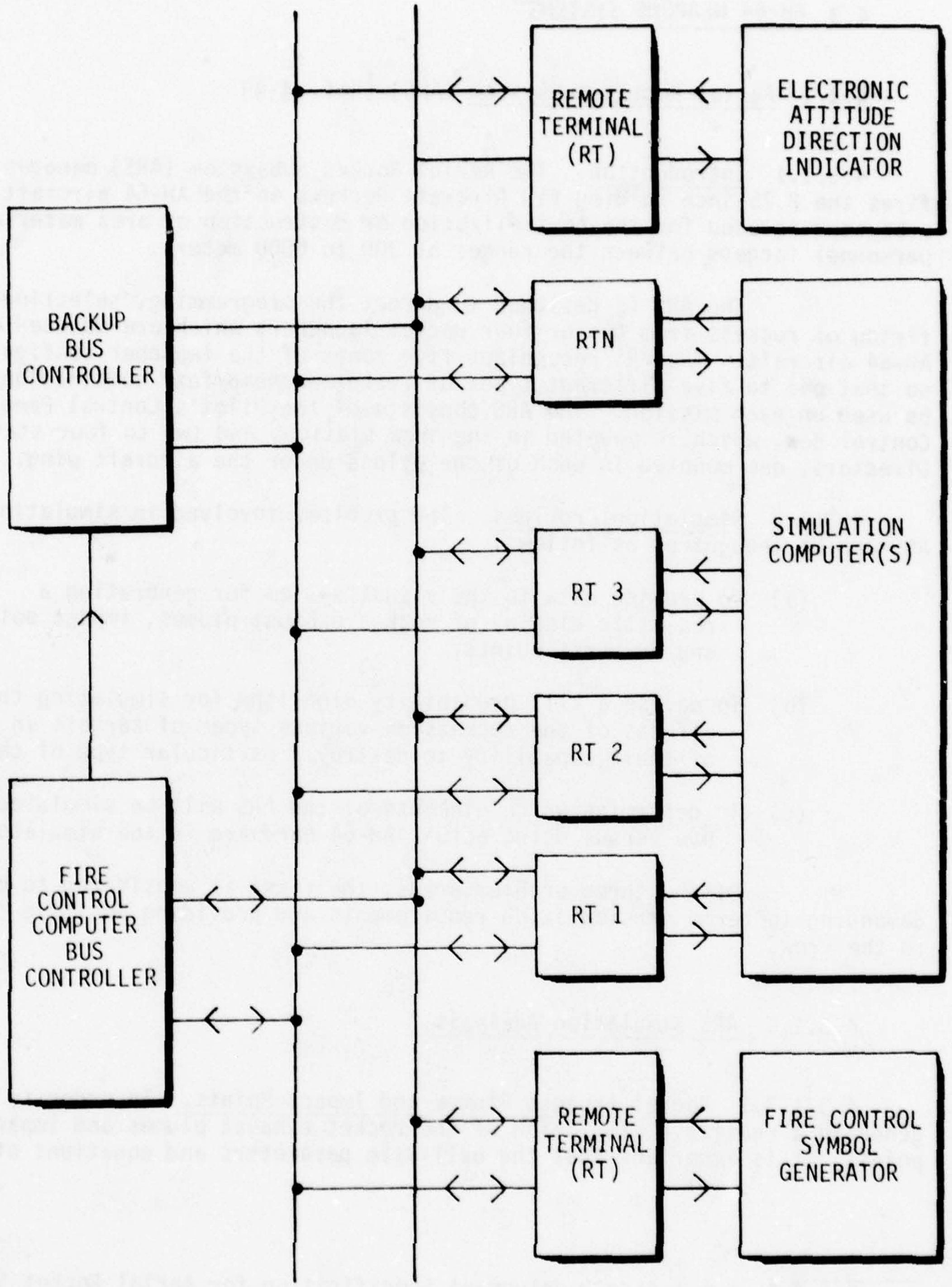

Figure 4-1 Partial System Block Diagram - Multiplex Data Bus System

4.3 AH-64 WEAPONS SYSTEMS

4.3.1 Aerial Rocket Subsystem (ARS) (Ref. 4-4)

4.3.1.1 Introduction. The Aerial Rocket Subsystem (ARS) manages and fires the 2.75-inch Folding Fin Aircraft Rockets on the AH-64 aircraft. The subsystem is used for the neutralization or destruction of area material and personnel targets between the ranges of 300 to 6000 meters.

The ARS is designed to direct the programming, selection and firing of rockets from two or four rocket launchers which are mounted on the AH-64 aircraft. The ARS recognizes five zones of the launcher configuration so that one to five different types of rocket/warhead/fuze combinations may be used on each mission. The ARS consists of the Pilot's Control Panel and Control Box, which is mounted in the crew station, and two to four station Directors, one mounted in each of the pylons under the aircraft wing.

4.3.1.2 Simulation Problems. The problems involved in simulating the ARS can be thought of as follows:

(a) To provide data to the visual system for generating a realistic display of rocket exhaust plumes, impact points and/or burst points.

(b) To devise a kill probability algorithm for simulating the effects of the rockets on various types of targets in terms of their capability to destroy a particular type of target.

(c) To determine which elements of the ARS will be simulated and how versus using actual AH-64 hardware in the simulator.

Of the three problem areas, the first is considered to be more demanding in terms of simulation requirements and providing positive training to the crew.

4.3.1.3 ARS Simulation Analysis.

4.3.1.3.1 Rocket Exhaust Plumes and Impact Points. In order to generate a realistic simulation of the rocket exhaust plumes and impact points, it is important that the ballistic parameters and equations of

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Ref.4-4. Prime Item Development Specification for Aerial Rocket Subsystem for YAH-64 Advanced Attack Helicopter, AMC-DP-AAH-H4003, Hughes Helicopters, Culver City, Calif., 1976.

motion of the rockets be mechanized in the simulator. Although this data has not been obtained as yet from the government or system manufacturer it is believed that some or all of this data exists or will eventually exist. The reason for this statement is that one of the functions of the AH-64 Fire Control Computer is to store ballistic parameters for the rockets and to compute azimuth and elevation aiming corrections for the rockets based on target range and line of sight angles, predicted trajectory and impact point. By inference, this means that the Fire Control Computer determines the required azimuth and elevation launch angles of the rockets to bring the impact point of the rocket, as determined from the trajectory, into coincidence with the target position. In the simulator based on the position of the AH-64 at the time of launching the rocket and the launch angles of the rocket, the simulation must compute the position of the rocket, in three dimensions x, y and z, along the rocket trajectory, convert the position of the rocket into the coordinate system of the visual system and output that data to the visual system. At the same time the simulation must compare, for a given x, y position of the rocket, the z value of the rocket with the z value of the terrain, including trees, buildings and targets so as to determine the rocket impact point and explosion and then provide this data to the visual system. Special types of rockets, such as those with a fuzed airburst warhead, must also be taken into account when determining where to position the explosion on the visual system.

The flight velocity of the rockets is unknown at present but is believed to be small, such that the position of the rocket can be computed and displayed at a rate of every 50 milliseconds or possibly slower, without causing an unrealistic display. However, depending on the mode and quantity selections made by the pilot on his control panel, eight or more rockets could be in flight at one time and would require their positions to be calculated at that computation rate. The position of the rocket would be calculated from the equations of motion which describe the trajectory of the rocket through the air. Inputs to this equation would be the position of the AH-64 at the time of launch, the groundspeed and attitude of the AH-64, the azimuth and elevation of the rocket launchers, the wind speed and direction. The outputs from this equation would represent the trajectory of the 'ideal' rocket through the air. Due to variations in the alignment of the rocket launcher tubes, vibrations of the AH-64, and the effect of the rotor downwash on the rockets as they leave the laucher tube, not all the rockets follow the trajectory of the ideal rocket. In practice the trajectory of the rockets tends to disperse away from the ideal trajectory so that the volume of space within which the trajectory of the rocket would occur tends to represent a cone with the apex being the position of the AH-64. The trajectory of any rocket within this cone appears to be completely random and cannot be represented mathematically.

To simulate this effect, it is proposed that a probability distribution be developed, in consultation with the U.S. Army which will define the percentage of the rockets launched whose trajectory falls within a cone of a certain angle. As each rocket is fired from the AH-64, a varying position bias would be added to the position of the rocket as calculated

from the equation of motion for the ideal rocket, in accordance with the probability distribution and the size of the cone. The ideal position plus the bias would then represent the 'true' position of the rocket.

For each iteration of the computer, the elevation component of the true rocket position would be compared with the elevation of the terrain to determine whether the rocket had impacted with the terrain. The true rocket position would then be output to the visual system with appropriate 'flags' set to indicate whether a rocket exhaust plume or an explosion should be displayed. The decision logic for the visual display would also take into account the special types of warheads such as the fuzed airburst and penetration types.

4.3.1.3.2 Kill Probability Algorithm. The impact point of the rocket vis-a-vis the position of the target will be a solution from the calculation of the rocket trajectory and impact point described herein. Therefore, it is possible to determine whether a rocket has physically hit a target. Even if this occurs, it does not necessarily follow that the target is completely destroyed. The destruction of a target depends on a number of factors:

- Lethality characteristics of the rocket
- The type of target
- The impact point of the rocket on the target
- The number of rockets that hit the target

To model all these factors in software would be too complex and costly. However, in consultation with the U.S. Army, a kill probability algorithm would be devised for simulating these factors for various types of targets. For example, a personnel carrier might be allocated a 40% probability of being completely destroyed when hit by a rocket. The kill probability would be implemented using a random number generator. Each time it was determined that a rocket had hit a target the random number generator would be read and if its value was less than 40% of the full-scale value then the target would be classified as having been destroyed.

4.3.1.3.3 Simulation of the ARS. The ARS consists of the Pilot's Control Panel and Control Box and the Station Directors. The operation of the ARS is mainly a series of logic decisions based on selections made on the Control Panel, firing commands from the crew controls and inputs from the Fire Control Computer. As the Station Directors are outside the cockpit area, their functions and operation will be simulated by software. For the Pilot's Control Panel and Control Box, it is not clear from the Hughes Subsystem Specification for the ARS whether this item is one unit or two physically separate units. However, for the simulator, the approach would be to use an actual AH-64 Rocket Control Panel and to simulate the logic

operations and microprocessor programs of the Control Box portion and interface to the Control Panel. This approach does have a drawback, namely that if there is future growth or changes envisaged to the functions of the ARS, then the simulation software has to be modified accordingly to reflect the changes. However, CAE believes that the design and development of this subsystem will be practically complete by the time the simulator is being produced and therefore changes to the subsystem will be unlikely.

The simulation of the ARS is not considered to be a critical problem area in the overall simulator and once a full data package for the ARS was made available the simulation would be straight forward.

4.3.2 Point Target Subsystem (PTS). (Refs. 4-1 and 4-5)

4.3.2.1 Introduction. The PTS consists of the Remote Hellfire Electronics, cockpit controls and displays and the Hellfire missiles and launchers. The subsystem is the primary armament on the AH-64 for the destruction of tanks and other hard, point-type targets. The PTS interfaces with the Target Acquisition Designation system (TADS), which provides pointing commands to the missile seeker; the Fire Control Computer, which provides control of the PTS operational modes and storage of laser codes; and the Integrated Helmet and Display Sight Subsystem (IHADSS), which also provides pointing commands to the missile seeker when selected by the crew. All interfacing is carried out via the MIL-STD-1553A multiplex bus. The missile seeker is a laser seeker with the eventual capability of employing either a radio frequency/infra-red seeker or an infra-red imaging seeker. The problems involved in simulating the PTS are the following:

(a) Determining the reference point on the terrain that is providing the reflected laser energy for the missile seeker.

(b) Modelling the seeker and flight control subsystems of the missile so as to compute the flight path of the missile.

(c) Generating a realistic visual display of the missile motor exhaust.

(d) Determining whether the missile hits the target.

(e) Simulating the functions and operation of the Hellfire Missile Equipment (HME) portion of the PTS.

Ref.4-5. Prime Item Development Specification Point Target Subsystem Specification, AMC-DP-AAH-H4001, Hughes Helicopters, Culver City, Calif.,1976.

4.3.2.2 PTS System Description. The Hellfire missile can be launched in one of three modes - direct, indirect and pseudo-indirect. In the direct mode, the missile locks on to the reflected laser energy before being launched. After launch, the seeker tracks the reflected laser energy and guides the missile to the target. If the reflected laser energy is discontinued, the missile flies according to its equations of motion until the reflected laser energy is reacquired and the seeker then tracks and guides the missile to the target. The laser energy is reflected from a point on the terrain that is being designated by either the laser on the AH-64 (autonomous mode) or a remote laser mounted on another air vehicle or operated by an infantryman (cooperative mode).

In the indirect mode the missile is launched with the helicopter masked from the target and the missile flies a preprogrammed trajectory before acquiring and locking on to reflected laser energy. The seeker then tracks the energy and guides the missile to the target. This mode relies on the availability of a remote laser designator.

In the pseudo-indirect mode, the missile is launched in the direction of the target and flies according to its equations of motion until the seeker acquires and locks on to the reflected laser energy and then the seeker guides the missile to the target. The mode can be used with either the laser on the AH-64 or a remote laser designator.

4.3.2.3 PTS Simulation Analysis. The first priority for the simulation is to determine the reference point on the terrain which is providing the reflected laser energy and when the reference point is being designated by a laser. For the direct mode, by monitoring the operation of the copilot/gunner (CPG) hand control which commands the missile seeker into the cage, laser scan or slave modes, and by monitoring the mode in which the laser is operating, it will be possible to determine the position of the reference point. If the missile seeker is in the slave mode, the AH-64 laser will be supplying pointing commands from either the laser designator in the autonomous Hellfire mode, or the laser tracker in the cooperative Hellfire mode. Hence, the laser simulation can provide the pointing commands and the position of the reference point to the Hellfire simulation (paragraph 4.4.3.2).

If the Hellfire is in the indirect mode it will be relying on a cooperative remote laser designator. The position of the reference point that is being designated by this remote laser can be determined by comparing the triservice codes for all targets with the code entered into the missile before launch. The triservice codes for the targets can be entered by the instructor in conjunction with his acting as the remote designator operator in any communications between the AH-64 crew and the operator. The position of the target whose code corresponds with that of the missile becomes the position of the reference point. If the missile is launched without a code being entered then the instructor will have to specify the reference point position to the simulation.

In the pseudo-indirect mode the target is sometimes designated to the missile seeker before launch although the seeker does not lock on. In this instance the reference point position can be determined as for the direct mode. If the target is not designated before launch a comparison of the missile code with the laser code will determine if the AH-64 laser is designating and hence the position is available from the laser simulation. If a remote laser is designating, a comparison of target codes with the missile code will determine the target that is being designated and therefore the reference point position.

For determining when the reference point is being designated, the operation of the laser trigger by the CPG will be monitored when the AH-64 laser is performing the designating. If a remote laser is designating the reference point, the instructor could be provided with controls to enter when the designator is operating or alternatively the simulation could assume that the remote designator is permanently operating.

In order to provide a realistic simulation of the flight path of the missile, which is needed for generating the visual display and for determining the missile impact point, the seeker and flight control subsystems and the equations of motion will have to be modelled in the simulator. A block diagram of the proposed model is shown in Figure 4-2.

If the reference point is being designated, the angular coordinates from the missile present position to the reference point would be computed and compared with the scan angles of the missile seeker, allowing for missile attitude and heading, to determine whether the seeker could sense the reflected laser energy. Included in this comparison would be the necessary computations to determine whether the reference point was obscured from the missile by terrain. If the reference point was in the field of view of the seeker, the off boresight angular errors to the reference point would be computed in the missile seeker axis system. If the reference point was not being designated or if the reference point was being designated but was not in the field of view, the angular errors would be set to zero.

The angular errors would then be resolved into flight control error commands in accordance with the mechanization used in the missile itself. Included in this mechanization would be a constant which could be varied by the instructor to simulate the effects of variations in received signal strength in different atmospheric conditions. The flight control error commands would be an input to the missile equations of motion model. The equations of motion for the direct, indirect and pseudo-indirect firing modes would be modelled from which the new missile position, attitude and heading would be calculated. The amount of motor propellant expended would also have to be modelled so as to determine if the missile failed to reach the reference point because of range limitations.

Each time a new missile position was calculated, the elevation of the missile would be compared with the elevation of the terrain underneath it to determine if the missile had impacted the ground. Then, the line of sight from the AH-64 to the missile would be computed to determine whether

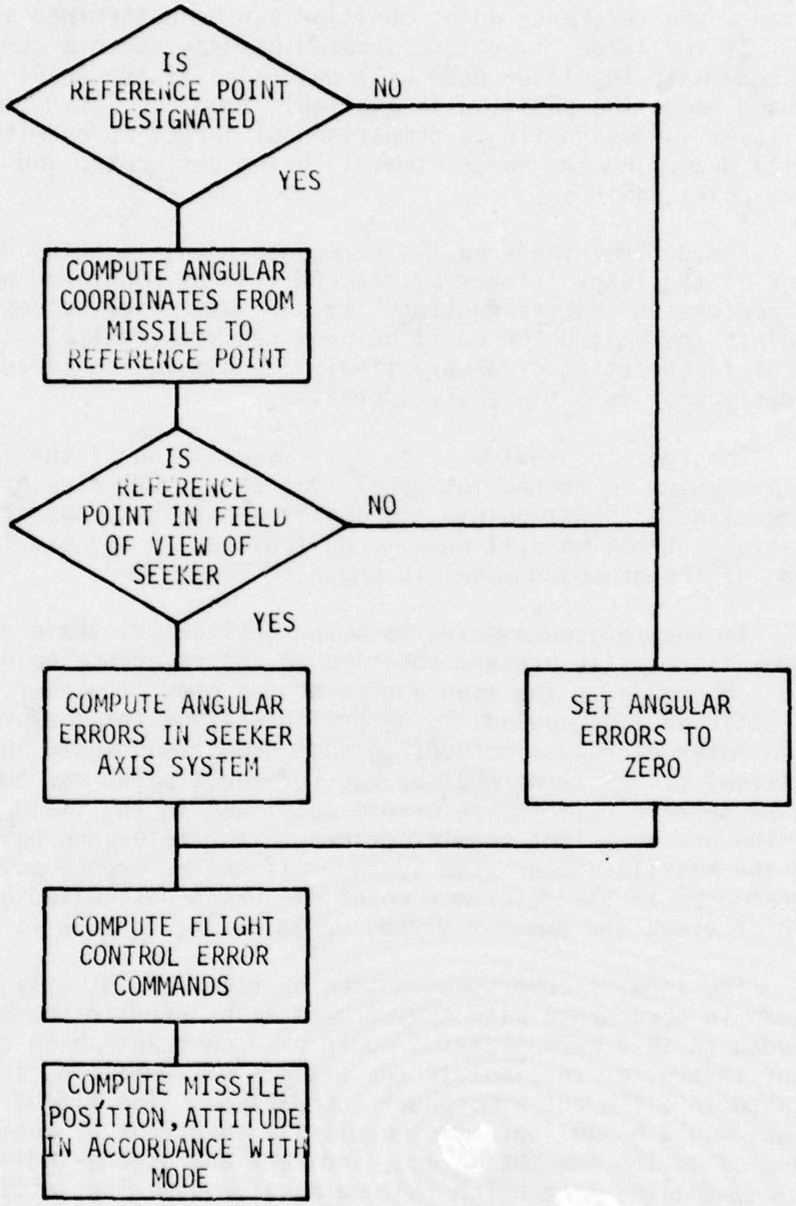

Figure 4-2. Block Diagram of Missile Seeker and Flight Control Model

the motor exhaust or the impact explosion, as the case might be, was visible to the crew. If it was visible to the crew, the missile position would be resolved into visual display system coordinates and output along with data concerning either the intensity of the motor exhaust required on the visual display or a simulated explosion required on the visual display.

If the reference point had been designated by a remote laser, its position and the impact point would be compared to determine whether the target had been hit and destroyed, because the reference point represents the target position. If the reference point had been designated by the AH-64 laser, the impact point would have to be compared with all target positions to determine target destruction, because the CPG might not have aimed the laser correctly at the intended target.

4.3.2.4 Hellfire Missile Equipment (HME). Of the various elements that comprise the HME portion of the PTS, the pilot and copilot/gunner Hellfire panels and their respective remote terminals for multipliexing the data onto the data bus will be actual aircraft hardware. Figure 1 of Ref. 4-5 implies that the remote terminals and the panels are separate units so that it is possible to monitor the data passing between the panel and the remote terminal if this is determined to be necessary when more details are available of the interface signals of the subsystem. If, however, the remote terminals are contained within the panels then this philosophy may have to be reexamined The other elements of the PTS will all be simulated. The logical functions and operation of the Remote Hellfire Electronics and the Launcher Electronics would be simulated by software and be interfaced with the TADS, IHADSS and FCC as required.

4.3.3 Area Weapon Subsystem (AWS). (Refs. 4-6 and 4-7)

4.3.3.1 Introduction. The AWS consists of a 30-mm Chain Gun, a turret assembly, an ammunition handling system, a turret control box, a gun control box and an infrared suppressor. The AWS interfaces with the armament control panels, crew controls and sighting systems, other weapon subsystems and the FCC. These other systems provide inputs to the AWS to position the turret and enable and control the firing of the gun.

The primary problems involved in simulating the AWS are those of generating a realistic visual display of the ammunition impact points and of devising a kill probability algorithm for simulating the effects of the ammunition on various types of targets, in terms of its capability to destroy that target.

Ref.4-6. Critical Item Development Specification for XM 230 (A/D) 30-mm Gun, AMC-DC-AAH-H4005, Hughes Helicopters, Culver City, Calif., 1976.

Ref.4-7. Prime Item Development Specification for Area Weapon Subsystem for Model YAH-64 Helicopter, AMC-DP-AAH-H4002, Hughes Helicopters, Culver City, Calif., 1976

The simulation of the functions and operation of the various elements of the AWS is important to the overall simulation but is not considered to be a problem area.

4.3.3.2 AWS System Design Analysis. To generate a realistic simulation of the ammunition impact points, it is important that the ballistic parameters and equations of motion of the ammunition be mechanized in the simulator. Although this data has not been obtained as yet from the government or system manufacturer, it is believed that some or all of this data exists or will eventually exist. The reason for this statement is that one of the functions of the AH-64 FCC is to store ballistic parameters for the 30-mm ammunition and to compute azimuth and elevation aiming corrections for the gun based on target range and line of sight angles, muzzle velocity, predicted trajectory and impact point. By inference, this means that the FCC determines the required azimuth and elevation pointing angles of the gun to cause the impact point of the ammunition (as determined from the trajectory) to coincide with the target position. In the simulator, based on the position of the AH-64 at the time of firing the gun and the pointing angles of the gun, the simulation must compute the position of the ammunition in three dimensions x, y and z, along the trajectory. Then, for a given x, y position of the ammunition, the simulation must compare the z value of the ammunition with the corresponding z value of the terrain, including trees, buildings and targets, so as to determine the ammunition impact point and then provide this data to the visual system.

As the ammunition used in the 30-mm Chain gun is not believed to include tracer, the only visual simulation requirement for the gun will be that of the impact of the ammunition on the terrain or a target which will cause either debris to be thrown up or the explosion of the target. This visual display will likely only be required for the magnified sight visual simulation although the destruction of the target will also be required on the out-the-window visual display.

The impact point of the ammunition will be calculated from the equations of motion which describe the trajectory of the ammunition through the air. Inputs to this equation will be the following:

- The position of the AH-64 at the time of launch
- The groundspeed and attitude of the AH-64
- The azimuth and elevation pointing angles of the gun
- The wind speed and direction
- Muzzle velocity

The outputs from this equation would represent the trajectory of the 'ideal' ammunition through the air. However, because of recoil loads and the lack of complete rigidity of the gun, vibrations of the AH-64, and the effect of the rotor downwash on the ammunition as it leaves the muzzle, not all the ammunition follows the trajectory of the ideal ammunition. In practice the trajectory of the ammunition tends to disperse away from the ideal trajectory so that the volume of space within which the trajectory of the ammunition would occur tends to represent a cone with the apex being the position of the AH-64. The trajectory of the ammunition within this cone appears to be completely random and cannot be represented mathematically. Consequently, the impact points of the ammunition on the terrain will tend to be random and to fall within a circle of a certain diameter whose center is the impact point of the ideal ammunition.

To simulate this effect, it is proposed to develop a probability distribution, in consultation with the U.S. Army, which will define the percentage of the ammunition which impacts within a circle of a certain diameter, relative to the impact point of the ideal ammunition.

For each iteration of the computer, having calculated the position of the ideal ammunition in space from the equations of motion, the elevation component of the ammunition position is compared with the corresponding elevation of the terrain at that position to determine whether impact with the terrain or a target has occurred. This process is repeated at each iteration until impact with the terrain. Then, based on the probability distribution, a position bias is added to the impact point of the ideal ammunition before transforming the impact position into the coordinates of the visual system and outputting the data to the display. For each subsequent piece of ammunition fired, a varying position bias is added to the impact point of the ideal ammunition, again based on the probability distribution to simulate the randomness of the impact point within the defined circle, and then the position data is output to the visual system. However, these impact points relative to the ideal impact point are only correct if there is no change in either the AH-64 position or the pointing angles of the gun during the burst of fire. If there is a change in any of these parameters then the impact point of the ideal ammunition must be recalculated.

The flight velocity of the ammunition and its variation with respect to time due to aerodynamic friction is unknown at present but it is believed to be initially of the order of 2000 feet per second. For a computer iteration rate of 50 milliseconds, the ammunition will move approximately 100 feet between position updates with progressively smaller increments as the flight velocity reduces during the terminal phase of its trajectory. Therefore, it should be possible to determine the impact point with an accuracy of ±50 feet or less and it is believed that this accuracy will be sufficient for the training purposes.

The gun is capable of a sustained firing rate of 725 ±25 shots per minute. This corresponds to approximately one shot being fired every 100 milliseconds. Therefore the simulation will be readily able to determine the impact point of the random pieces of ammunition and output this data to the visual system.

The impact points of the ammunition vis-a-vis the position of the target that was fired at will be a solution from the calculation of the ammunition impact points described above. Therefore, it is possible to determine whether the ammunition has physically hit a target. Even if this occurs, it does not necessarily follow that the target is completely destroyed. The destruction of a target depends on a number of factors:

- Lethality characteristics of the ammunition
- The type of target
- The impact point of the ammunition on the target
- The number of ammunition rounds that hit the target

To model all these factors in software is complex and costly. However, these factors can be simulated by devising a kill probability algorithm, in consultation with the government, for various types of targets. For example, a truck might be allocated a 60% probability of being completely destroyed when hit by an ammunition round. The kill probability can be implemented using a random number generator. Each time it was determined that a round has hit a target the random number generator is read and if its value is less than 60% of the full-scale value then the target is classified as destroyed.

The simulation of the functions and operation of the AWS will be as follows:

- Modelling the logic that controls the operation of the AWS.
- Accepting inputs from other simulated systems, crew controls and the Fire Control Computer.
- Providing outputs to the Fire Control Computer and the gun rounds remaining display.

Assuming a full data package on the functions and operation of the AWS is available it is believed that the simulation of these functions and operation will not present a problem.

4.4 TARGET ACQUISITION DESIGNATION SYSTEM (TADS) (Ref. 4-8 and 4-9)

4.4.1 Introduction. The TADS consists of a day viewing subsystem (Direct View and TV), night viewing subsystem (FLIR), laser rangefinder/designator, laser tracker, and stabilization and tracking subsystem. The viewing subsystems enable the operator to visually search for and acquire targets for day/night engagement at specified ranges and can be cued by the IHADSS and navigation system.

4.4.2 TADS Visionic Systems. The problems involved in simulating the viewing subsystems of the TADS are those of providing the pointing angles and field of view to the visual simulation system and simulating the autotracking modes of the viewing subsystems. Analysis of generating the visual displays for the various viewing subsystems are included in paragraph 5-10.

4.4.2.1 System Design Analysis. For the viewing subsystems the simulation will accept inputs from the gunner and pilot control panels, the IHADSS and the gunner's hand control. Based on the various inputs, the simulation will determine which optical sensor is selected for display on the gunner's boot display and whether wide, intermediate or narrow field of view has been selected. Inputs from the gunner's hand control and the IHADSS will be integrated and resolved through aircraft attitude and heading to determine the position of the boresight of the selected sensor with respect to the axis of the visual system, taking into account any limitations due to reaching the gimbal limits of the sensor turret. This data can then be transferred to the visual system for use in generating the required visual display. In addition this data will be output to the symbology generator.

The FLIR and TV systems employ an autotrack facility. The gunner manually points the boresight of the sensor at the required target and then selects autotrack. This can be simulated by comparing the boresight of the sensor with the line of sight to all targets within range of the sensor and, having found a comparison, tracking that target by modifying the boresight position of the sensor to account for changes in position of the target and the AH-64. The resulting new boresight position can then be fed to the visual simulation system. In practice, the operational autotrack subsystem can lose lock when viewing complex scene conditions. In the simulator it is proposed that the instructor be provided with a control to cause the simulation to simulate a breaklock condition, with the appropriate

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Ref.4-8. Prime Item Development Specification for TADS, DRC-DP-AAH-4020A, U.S. Army Aviation Systems Command, St. Louis, 1976.

Ref.4-9. Prime Item Development Specification YAH-64 Design Requirements for TADS, DRC-DP-AAH-4020A, Appendix II, U.S. Army Aviation Systems Command, Saint Louis, 1976.

indications to the gunner. Based on the gunner's action after breaklock, the system can then go back into the autotrack mode. While the autotrack facility is engaged, the simulation must check that the target being tracked does not become obscured from the AH-64 and cause the autotracking subsystem to lose lock. This can be done by performing a line-of-sight calculation from the AH-64 to the tracked target and checking for terrain obscuration.

4.4.3 Laser Rangefinder/Designator/Tracker.

4.4.3.1 Introduction. The Laser Rangefinder/Designator/Tracker (LRF/D/T) comprises part of the AH-64 Target Acquisition Designation System (TADS) and is used for the following:

- To detect and track targets that are being illuminated by remote laser designators.
- To designate targets for guiding semiactive terminal homing weapons.
- To provide target range and pointing information for use in gun and rocket weapons delivery.

The LRF/D/T interfaces with the sighting systems on the AH-64 which provide cueing commands, with the Hellfire Missile for target handoff, and with the FCC to provide range and pointing angles for weapon delivery computations.

The problems involved in simulating the LRF/D/T are those of determining the range to the point on the ground that is being illuminated by the laser based on the commanded pointing angles (Laser Rangefinder), determining which target is being illuminated by a remote designator and tracking that target (Laser Tracker), and providing pointing angle and position data to the Hellfire missile to simulate the target designation function (Laser Designator).

4.4.3.2 System Design Analysis. The Laser Rangefinder provides range and pointing angle data to the FCC for use in gun and rocket weapons delivery. To simulate this function the pointing angles of the laser when it is fired must first be determined. The pointing angles can be determined from the input cueing commands from other sighting systems, the attitude and heading of the AH-64 and the stabilization limits. By resolving the cueing commands through the AH-64 attitude and heading and allowing for the stabilization limits, the pointing angles with reference to the local horizontal and vertical axis can be determined. The pointing angles describe the line of sight from the AH-64 to the point on the terrain illuminated by the laser rangefinder. The range to the point on the terrain can be determined by comparing the position of the laser beam in space with the terrain it is traversing.

The data base of the visual system will describe the terrain, including vegetation, buildings, and targets in three dimensions relative to an origin. The laser beam can be resolved into a set of three dimensional positions by stepping along the beam at intervals corresponding to the range accuracy of the rangefinder and transforming into the same axis system as the data base. For a given beam position, a comparison between the elevation of the beam and the elevation of the terrain will yield the point on the terrain being illuminated by the laser and hence the range can be determined.

The comparison between the elevation of the beam position and the elevation of the terrain is continued until either a hit is determined or the maximum range of the laser is reached. Having determined the hit position the range and pointing angles can be supplied to the FCC. After initial contact with the hit position any changes in range and pointing angles due to movement by the target or the AH-64 can be calculated by trigonometry and by ensuring that the commanded pointing angles still aim the laser at the hit position. However, any change in position by the target or the AH-64 means that the line of sight will have to be recomputed and compared with the terrain to ensure that the target has not become obscured by any terrain. It is believed though that this calculation can be done at a much slower rate than the initial calculation to determine the hit position without reducing the quality of the simulation.

In practice the copilot/gunner sees the target range appear on his TADS display almost instantaneously after first pressing the laser trigger, with the delay being of the order of 1 millisecond. In the simulator it is not possible to display the range to the gunner at the same speed, because of delays in recognizing the operation of the laser trigger and processing the line of sight to determine the hit position. It is estimated that the delay in the simulator will be between 200 milliseconds and one second. Although this delay may seem excessive compared to the delay in the AH-64, it is believed that this delay will not be noticeable to the copilot/gunner and will not detract from the training realism. Thereafter, any change in laser range due to movement of the AH-64 or the target will be updated every computer iteration.

Because the laser beam is not infinitely small and has some divergence, the laser beam will generate multiple returns, depending on the nature of the terrain between the AH-64 and the target and the reflective characteristics of that terrain. These multiple returns can be simulated by allowing for the horizontal and vertical dimensions of the beam when comparing the beam elevation with the terrain elevation to determine a hit point. The return which provides the range for the FCC and the TADS display will be determined from the reply mode selection by the copilot/gunner.

The Laser Tracker functions will be simulated by comparing the laser code selected by the crew with the laser code allocated to each target by the instructor, for those targets that are within the field of view of the tracker in either the autosearch or manual search mode. Having determined which target is being designated the line of sight to the target will be checked to ensure that it is not obscurred by terrain and is within range, before providing the following:

. The Laser Tracker lock on indication to the crew

. The line of sight data to the TADS optical sensors

. The line of sight and postion data to the Hellfire simulation (paragraph 4.3.2)

To model the effects of meteorological visibility, target to designator and target to laser tracker aspect angles on the laser tracker performance presently appears too complex and costly. Therefore the simulation will assume that the laser tracker receives sufficient energy to lock on although the instructor could be provided with an override capability in order to increase the training task difficulty.

The Laser Designator function shall be simulated in the same manner as the Laser Rangefinder except that the data will be transmitted to the Hellfire simulation programs instead of to the FCC. The data that will be transmitted to the Hellfire simulation will be the position of the point on the terrain that is being designated and the pointing angles to it. The rest of the simulation discussion presented herein for the Laser Rangefinder is applicable to the simulation of the Laser Designator.

4.5 INTEGRATED HELMET AND DISPLAY SIGHT SYSTEM (IHADSS).(Refs.4-1 and 4-10)

4.5.1 Introduction. The Integrated Helmet and Display Sight System (IHADSS) consists of two helmets, each having mounted on it a visor, communications equipment, Helmet-Mounted Display (HMD), Helmet-Mounted Sight (HMS) and a tracker and sighting reticle which are controlled by alignment panels and fixtures that are also a part of the IHADSS. The IHADSS interfaces with other fire control elements and serves as a head-mounted sighting system to align weapons and sensors to controlled positions. The pilot's IHADSS is used as the primary pilot day and night fire control headup display for firing rockets, missiles and guns.

Ref.4-10. Prime Item Development Specification for IHADSS, AMC-DP-AAH-H3005, U.S. Army Aviation Systems Command, St. Louis, 1976.

In view of the fact that it is proposed to use the complete aircraft hardware for the IHADSS in the simulator the only problem area expected is the interface to the IHADSS and the monitoring of the data on the interface.

4.5.2 IHADSS Design Analysis. In view of the complexity of the IHADSS, it is believed that the use of actual aircraft hardware is cost effective and produces the least technical risk. This includes the helmets, visors and angle sensors as well as the HMD and HMS electronics and the HMD alignment panel.

The IHADSS interfaces with the following:

- The TADS and PNVS FLIR sensors
- The Fire Control Symbol Generator
- The FCC
- Pilot and gunner controls.

In view of the specialized nature of the Fire Control Symbol Generator it is proposed that the actual aircraft hardware be used in the simulator so the interface to the IHADSS will be as in the AH-64. However, it may prove necessary to monitor the interface between the IHADSS and Fire Control Symbol Generator for use by other simulated systems. Using this approach any growth in the capability of the Symbol Generator on the AH-64 can be readily introduced in the simulator.

The FCC and pilot and gunner controls are all expected to be actual aircraft hardware so the interface to these systems will be as in the AH-64 with the possibility that monitoring of some or all of the signals may be required.

4.6 RADAR WARNING SYSTEM (RWS). (Ref. 4-1)

4.6.1 Introduction. The AH-64 has the AN/APR -39(V)1 Radar Warning Set (RWS) installed. The set comprises a CRT display and a control panel which are located in the pilot's cockpit, a processor/comparator unit and antennae which are located external to the cockpits. The RWS provides visual and aural indications to the pilot that the AH-64 is being illuminated and tracked by 'threat' radars and may also provide indications of when a radar guided missile has been fired at the AH-64. The unit interfaces with the communication system by providing two audio signals, one being an alarm tone and the other a signal representative of the amplitude and pulse repetition frequency of the radar signals being displayed.

The primary problem concerning the AH-64 RWS is that of deciding which elements of the aircraft hardware are to be used in the simulator and hence what simulation hardware and software is required to drive the aircraft hardware. A second problem is that of determining when the signals from a particular threat radar should be activated. This is a function of the relative position of the AH-64 and the threat radar and the terrain between them.

4.6.2 RWS System Design Analysis. The only data that CAE has received concerning the AN/APR-39 (V) 1 RWS is the brief description contained in Ref. 1. CAE appreciates the problems involved in supplying data concerning this classified item of equipment and the classified data for the characteristics of the threat radars to be found in a typical battle situation. However, it follows that some of the assumptions in the following discussion may be erroneous.

The RWS consists of a display, control unit, processor/comparator and the antenna receivers. The antenna receivers sense the radio frequency signals from the threat radars and converts them to video frequency signals which are transmitted to the processor/comparator. The processor/comparator processes the received signals and then outputs signals to the display which indicate the direction and type of the threat radar. The type of threat radar is determined by comparing the input video frequency signals with the processor/comparator library of expected threat signals and then coding the output signals to the display accordingly. In addition, the amplitude and PRF characteristics of the threat radar are transmitted to the communications system to generate audio alarm signals.

The alternative approaches for simulating the RWS are as follows:

(a) Injecting radio frequency signals into the receivers and allowing the receivers and processor/comparator to operate as in the AH-64.

(b) Injecting video frequency signals into the processor/comparator and allowing it to operate as in the AH-64.

(c) Driving the display and communication system directly from the the simulation hardware.

CAE believes that the best approach for simulating the RWS is to drive the RWS display and the aircraft communication system directly from the simulation hardware. A block diagram of the proposed system is shown in Figure 4-3. Under the control of the simulator computer, the symbol generator would generate the requisite symbols on the RWS display, which would be the aircraft CRT, and the programmable audio generator would generate

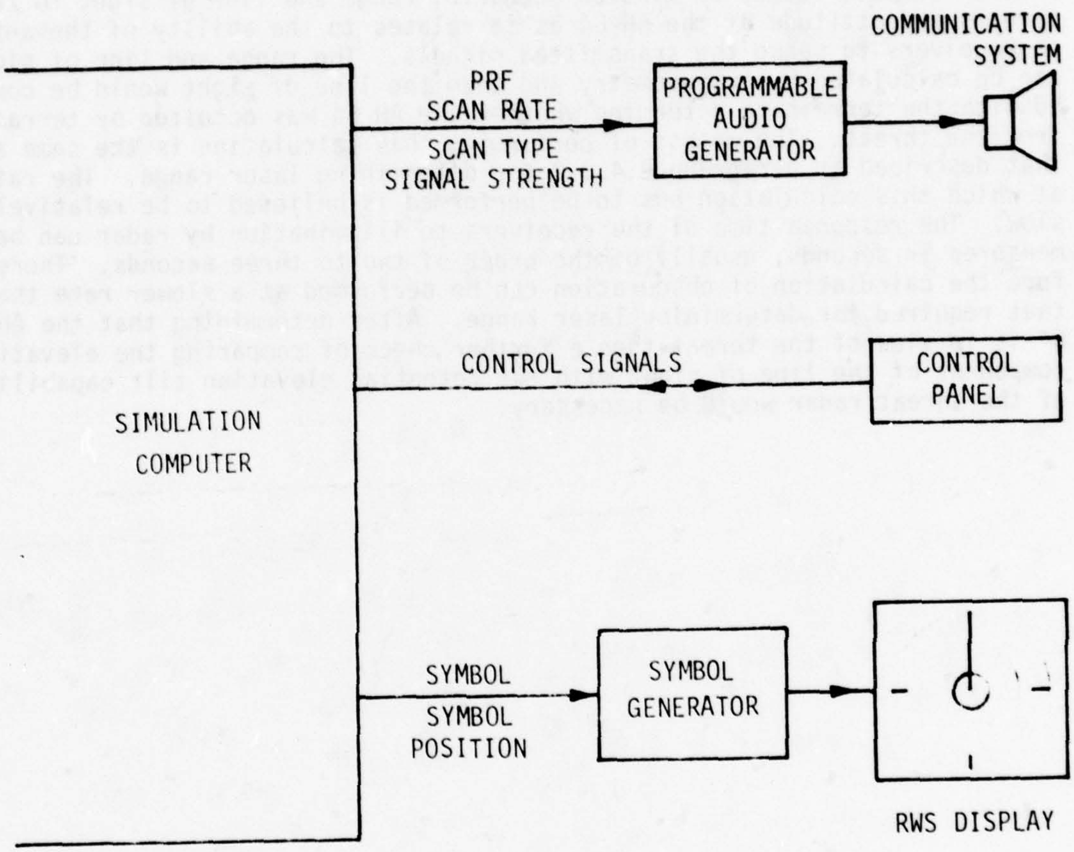

Figure 4-3. Block Diagram of RWS Simulation

audio signals, with PRF and amplitude representative of the received radar signals, for injection into the communication system.

Control of the simulation hardware would be performed by the simulation computer based on mission scenario, range and line of sight to the threats and attitude of the AH-64 as it relates to the ability of the antenna receivers to sense the transmitted signals. The range and line of sight can be calculated by trigonometry and then the line of sight would be compared with the terrain to determine whether the AH-64 was occulted by terrain from the threat. The method of performing this calculation is the same as that described in paragraph 4.4.3.2 for determining laser range. The rate at which this calculation has to be performed is believed to be relatively slow. The response time of the receivers to illumination by radar can be measured in seconds, usually of the order of two to three seconds. Therefore the calculation of obscuration can be performed at a slower rate than that required for determining laser range. After determining that the AH-64 is in view of the threat then a further check of comparing the elevation component of the line of sight with the potential elevation tilt capability of the threat radar would be necessary.

SECTION 5

VISUAL SYSTEM

5.1 VISUAL SIMULATION REQUIREMENTS

5.1.1 Flying Requirements. For the purposes of AH-64 FWS visual design, it is assumed that pilots will be proficient in all aspects of NOE flight before graduating to the AH-64. Basic NOE training is presumably done in relatively inexpensive helicopters, graduating to UH-1's, where training can be obtained on both helicopters and simulators. Once a pilot has learned to fly one type of helicopter well, we believe he is able to fly another type without great difficulty. The learned motor skills used in flying helicopters, therefore, must vary little from machine to machine.

The visual cues which the pilot requires when flying NOE seem to be parallax and texture gradient. Dr. John Barnes at Human Engineering Laboratories (HEL) verified the importance of parallax in a study analyzing pilot's eye movements during helicopter flight (Ref.5-1). Dr. Kent Kimball at Army Research Laboratory noticed that pilots using the AN/PVS-5 night vision goggles performed quite adequately in heavily treed areas giving many parallax cues. However, they had trouble in open grassy areas because of confusing texture cues caused by the noise and grain of the goggles.

Providing parallax and texture cues in a model board system is relatively easy if the scale is appropriate. It should be noted, however, that a reverse texture gradient is created at very low altitudes because of the depth of focus problem of the optical probe. The number of parallax cues should therefore be maximized whenever possible. Some present Computer Generated Image (CGI) systems can give good texture gradient cues but may suffer from lack of parallax cues at ground level. The choice of model board or CGI will be discussed later. The choice regarding flight should be based on the premise that NOE flying will not be taught in the simulator but that the visual system must allow NOE flight over the entire playing area. It should also allow flight at higher altitudes and practice in nontactical helicopter maneuvers.

5.1.2 Navigational Requirements. NOE navigation is a complex science, involving topography, hydrography, and a high level of perceptual skill. It is doubtful that sufficient detail could be put into any type of visual system that would enable navigation to be taught. The army has had considerable success with its current MAITAC navigation courses using film and slide presentations. It would appear that navigation should not be taught on the simulator but by the MAITAC system. Sufficient detail must, however, be incorporated into the model or data base to allow navigation over the entire playing area while flying NOE.

Ref.5-1. Barnes, J., Analysis of Pilot's Eye Movements During Helicopter Flight, U.S. Army HEL, Technical Memorandum 11-72, Aberdeen Proving Ground, 1972.

5.1.3 Target Simulation Requirements. There are two distinct tactical situations involving target acquisitions:

(a) The AH-64 crew knows fairly accurately the position and nature of the target.

(b) A more volatile situation exists in which only the general direction of the main enemy threat is known and individual enemy threats can appear from anywhere.

Army doctrine would probably discourage the use of the AH-64 in the latter situation on the grounds that it is too dangerous and would lead to a high loss of helicopters and men. Although not a primary task, training in the simulator for such a situation may be very effective in developing the various motor skills for both pilot and gunner which will enable them to survive on the battlefield.

The two situations present different problems to the visual system and will be discussed separately.

5.1.3.1 Prime AH-64 Missions. The prime mission of the AH-64 is to kill tanks with a high ratio of kills to losses. From discussions with Army personnel we believe that this will be achieved by the 'standoff' technique, in which the tank is engaged at between 3000 and 5000 meters, rendering the tanks weapons ineffective against a helicopter. Although a tank will subtend an angle of about five minutes of arc at 3000 meters and should be detectable according to the Johnson criteria, providing sufficient contrast between tank and background is available, experience has shown that the unaided human eye has little chance of detecting a stationary tank at this range. Scout helicopters will therefore be used to find the tanks and relay the information to the AH-64. The preferred tactical mission would proceed as follows:

(a) Following reports of enemy tanks in a particular area from a reconnaisance flight, a team of two AH-64's and one scout would proceed to the attack area. Larger teams could be sent if necessary, but the ratio of two AH-64's to one scout would probably be maintained.

(b) The AH-64's would wait at a 'holding' area until the scout had located the tanks and had determined a suitable attack position.

(c) The scout would then direct the AH-64's to the attack position, using radio communication or, if the use of radio was unavailable, would actually come back to the holding area and guide the AH-64's to the attack position. The scout may even reconnoiter the route from the holding area to the attack positions to ensure that no enemy threats are around.

(d) Once the AH-64's are in the attack position, the scout would pinpoint the tank position, possibly using his own laser rangefinder and a digital link between the scout computer and the AH-64 computer. The copilot/gunner would align the TADS with the tank position and have his head in the boot as the helicopter unmasks in order to acquire and identify a tank, select the appropriate mode of operation, and fire the missile in the shortest time possible. This phase of the mission would require good teamwork not only between the pilot and copilot/gunner of each AH-64 but also between the crews of the AH-64's involved in the attack. The various modes of operation for the Hellfire missile are discussed in Section 4.

The mission just described can be called the offensive or perhaps counteroffensive tactic. The other important mission is the defensive role, in which the AH-64's attempt to halt a massive advance of enemy armor. In this situation, the position of the tanks will be known, and the tanks will be quite visible because of their movement and the debris thrown up by the tracks, making the scout's role less important. No enemy threats will be expected to appear between the FARRP and the attack positions, so that the mission becomes a straightforward low-level or NOE flight between FARRP and the attack position, followed by acquisition and destruction of targets.

5.1.3.2 Acquisition of Target During Prime Mission. The significant fact in both these missions is the unimportance of the unaided eye when acquiring the target. Even in the defensive mission, when the debris and dust thrown up by the tanks and the movement of the tanks make their presence visible at 4000 meters, the copilot/gunner will have his head in the boot, looking through the low power optics in the expected direction of the enemy, when the AH-64 unmasks. Don Checkwick at PMTADS made it quite clear that the copilot/gunner would rarely use his unaided eye when searching for targets. Only on a very clear day, when looking for moving targets in dusty terrain, would the unaided eye match the capability of the TADS.

Our first contact with pilot instructors at Fort Rucker led us to believe that the opposite was in fact true. However, subsequent discussions at Fort Rucker and at the Aberdeen proving ground with Dr. John Barnes confirmed Don Checkwick's opinion, at least as far as tanks at 3000 - 5000 meters are concerned. Cobra copilot/gunners using the low-power TOW sight are actually able to acquire targets sooner than scout observers using their unaided eyes. Experiments by Dr. John Barnes on target detection during the HELHAT and HELCAT projects showed that the unaided eye performed rather poorly during NOE flight. The average target detection ranges for pattern-painted tanks during route reconnaissance was about 800 meters, and the average detection time during POPUP maneuvers was 50 seconds for pattern-painted tanks at 800 meters. Performance against camouflaged tanks was significantly worse.

5.1.3.3 Methods for Simulating Target During Prime Mission. The foregoing discussion has attempted to show the difficulty of searching for tanks at ranges in excess of 3000 meters with the unaided eye, an opinion held by many people in the Army.

In the simulator, therefore, it is unnecessary and perhaps even unwise to try to insert long-range targets into the window displays. Dust, smoke, muzzle flashes, rocket plumes, etc., should be shown and can be simulated in both CGI or solid model systems. It may even be advantageous to allow the instructor to insert a symbol in the window display to show either trainee the position of the target.

The TADS display, however, must show the targets and be sufficiently realistic to train the copilot/gunner in the correct mode of operation for a particular situation. For reasons that are dealt with in TADS (see paragraph 5.6), the imagery has to be computer-generated even in the solid model approach. It is of course difficult to relate realism with CGI, and it must be understood that 'sufficiently realistic' implies that the TADS simulation will apply stimuli to the eye/brain combination that are sufficiently similar to those obtained from the real TADS and that the same motor skills are used in the simulator as are used in the AH-64 itself. A learned motor skill firmly fixed in the brain is difficult to modify, and it may also be true that original motor patterns are never completely forgotten. A good example of this is shown by the automobile driver. A really good driver controls his vehicle through a series of learned motor skills which become second nature to him. If, however, he has been driving a car with a floor-mounted gear shift for many years and changes to a car with a column-mounted gear shift lever, he experiences considerable difficulty in learning to change gears. Even when he has mastered the new skill to the point at which it can be called a motor pattern, a slight trace of the original motor pattern is often present.

The use of the TADS to acquire, identify, and destroy a tank is a complex procedure. This procedure employs various motor skills linked together and controlled by many feedback paths stimulated almost entirely by the image in the TADS. Several external stimuli, such as motion, pilot communications, etc., will have an effect on the overall procedure, but the visual sensations are the most important. Therefore, it is necessary to stimulate correctly those parameters of each mode of operation which control the feedback paths. Having an increasing amount of detail in the target for the higher magnification modes is an obvious example. A less obvious one would be the correct simulation of lag in the TV camera when motion or vibrations are present in the image. The correct simulation of FLIR during daylight conditions and the near IR response of the TV camera should be taken into account. All of these can be accomplished by using CGI. The one parameter that is a cause for some concern is the high resolving power of the Direct View Optics (DVO) relative to the TV.

The recommended design for the TADS display is given in paragraph 5.6. The same high-resolution shadow mask CRT will probably be used for both direct optics and TV-type imagery. The direct optics will be colored, whereas the TV imagery will be monochrome. The inherent resolution in the simulator will be the same, whereas the direct optics should have approximately a resolution six times better to reflect the real world. The target can be made slightly larger in the DVO and have a color contrast greater than normal. This is probably sufficient for the low-power optics, where detection is the prime concern and there is no comparable TV view. The high-power DVO will have a magnification comparable to the low-power TV and, if atmospheric conditions permit, should show far greater detail. The basic CRT, using the Johnson criteria (Ref. 5-2) will barely be capable of identifying a tank at 4,000 meters even with a 50% increase in target size. The only acceptable solution seems to be to use an insertion technique by which the target is generated on a different CRT with sufficient detail and superimposed on the background image. The suggested approach is described in detail in paragraph 5.6. CGI lends itself to such treatment since the occulting will occur naturally. Problems occur when dealing with multiple moving targets, and in this area further study will have to be pursued before an optimum solution is reached.

5.1.3.4 Target Detections During Other Missions. When flying NOE in unsecured terrain, the crew must be constantly on the alert for enemy threats. In forest areas such as at Fort Bragg, a confrontation with enemy ground troops would occur at distances of less than 200 feet. Survival in this kind of situation depends on fast reaction times coupled with good teamwork. The identification of the target probably occurs at the same time as the detection. The limited resolution of the window display for the visual is sufficient to identify a group of soldiers at 300 feet. This type of threat could therefore be simulated very readily together with appropriate weapon effects.

Missions against lightly armored truck convoys would probably be carried out at close ranges, using rockets and cannons, and here again the resolutions of the display will allow recognizable targets. Trucks could be identified at ranges of 1000 feet and the effects of near misses evaluated.

Missions involving the control of friendly artillery and the observation of weapon impact would be done in a popup maneuver, with the copilot/gunner looking in the TADS boot. Only weapon signatures need be shown in the window display, mainly for the benefit of the pilot.

Ref. 5-2. Johnson, J., Image Intensifier Symposium, Fort Belvoir, October 1958.

5.2 FIELD OF VIEW (FOV)

5.2.1 General. In the design of a visual system for flight simulation, an area of high priority is the selection of the FOV to be displayed to the pilot. The determination of this FOV is dependent upon three factors: visual and perceptual requirements of the human observer, the FOV visible from the aircraft cockpit, and the availability of hardware to display the preferred FOV.

The capabilities of the human observer dictate the primary requirements for any visual system. The system must present to the pilot sufficient visual information to allow him to perceive cues of height, speed, and aircraft attitude that are compatible with his normal real-world experience. The system must also avoid the presentation of spurious visual information that conflicts with his experience or distracts him in the execution of the tasks. One of the most important facts that has emerged from studies of visual perception is that motion cues are strongly dependent on peripheral vision (Ref.5-3). Indeed, this phenomenon is commonly observed in visual flight trainers having a conventional 45^{o} horizontal FOV. Pilots find that the simulator flies 'too slowly' and height/distance judgments are often distorted as a result of the limited FOV. Conversely, in very wide FOV simulators such as the USAF's ASPT or SAAC, the wraparound vision field is known to give stronger attitude and rate cues than the hydraulic motion system.

Figure 5-1 is a plot of the instantaneous binocular vision field. As can be seen, the human visual field covers approximately 210^{o} at any given moment. However, the amount of information detected by the eyes and, therefore, required by the eyes varies over the instantaneous FOV as a function of both binocular effect and visual acuity. The unshaded area in Figure 5-1 represents the instantaneous FOV seen by both eyes simultaneously. Information contained in this region, approximately 115^{o} wide, can be perceived in three dimensions, or 'stereo'. Such information exhibits inherent cues as to distance and is therefore more powerful than the monocular information outside this field. Furthermore, as can be seen from Figure 5-2, the visual acuity of the eye drops off rapidly from the center of the FOV from about one arc minute at 0^{o} to about 100 minutes at 60^{o}. Thus very little information is required at the edge of the field. Although the optimum visual system should provide for an instantaneous FOV of 210^{o}, it is apparent that this figure may be reduced substantially, to perhaps 115^{o}, with little loss in perceived information (with the possible exception of speed cues).

Ref.5-3. Junker, A., and Price, D., Comparison between a Peripheral Display and Motion Information on Human Tracking about the Roll Axis, AIAA Visual and Motion Simulation Conference, Dayton, 1976.

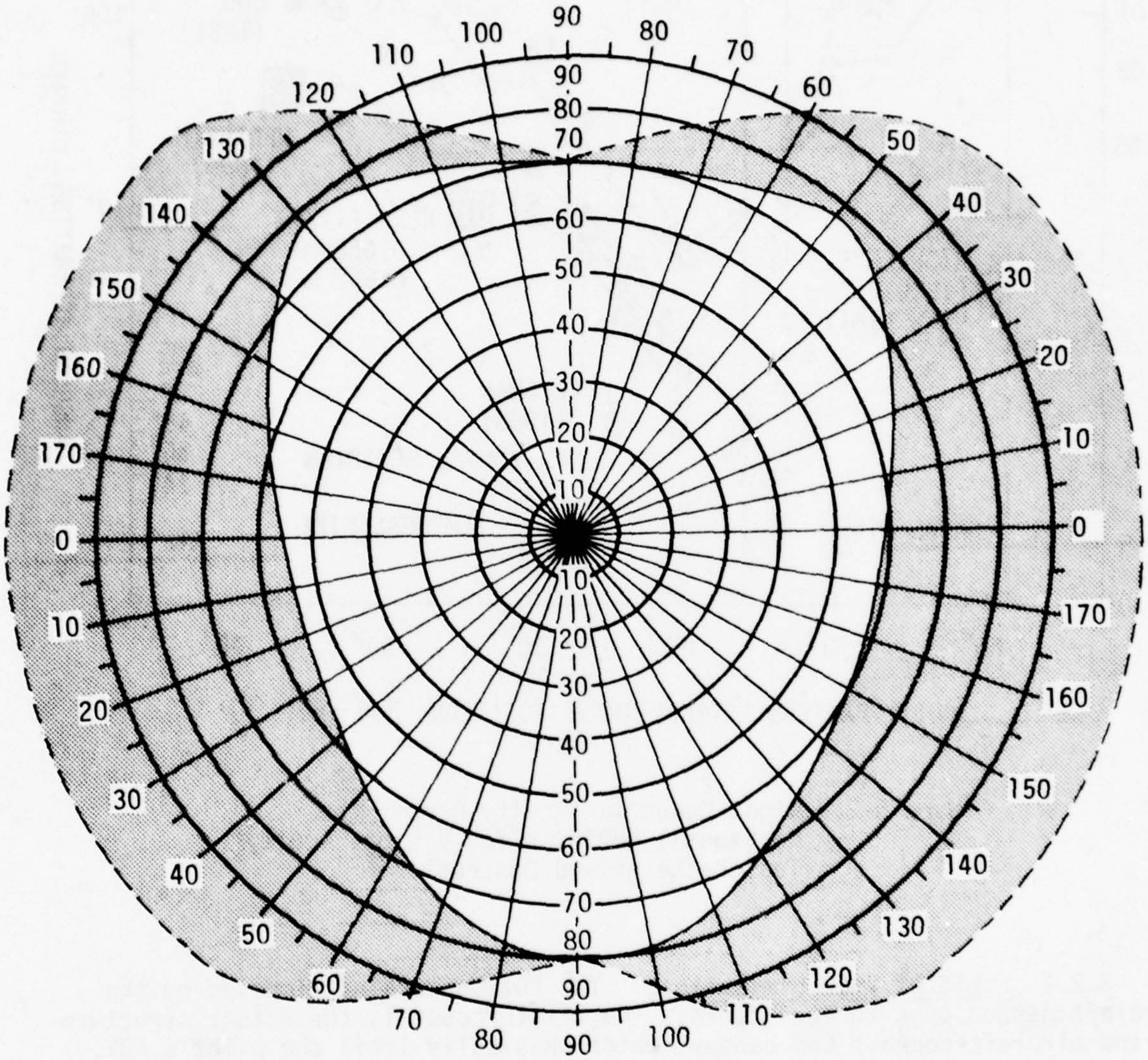

Figure 5-1. Binocular Visual Field

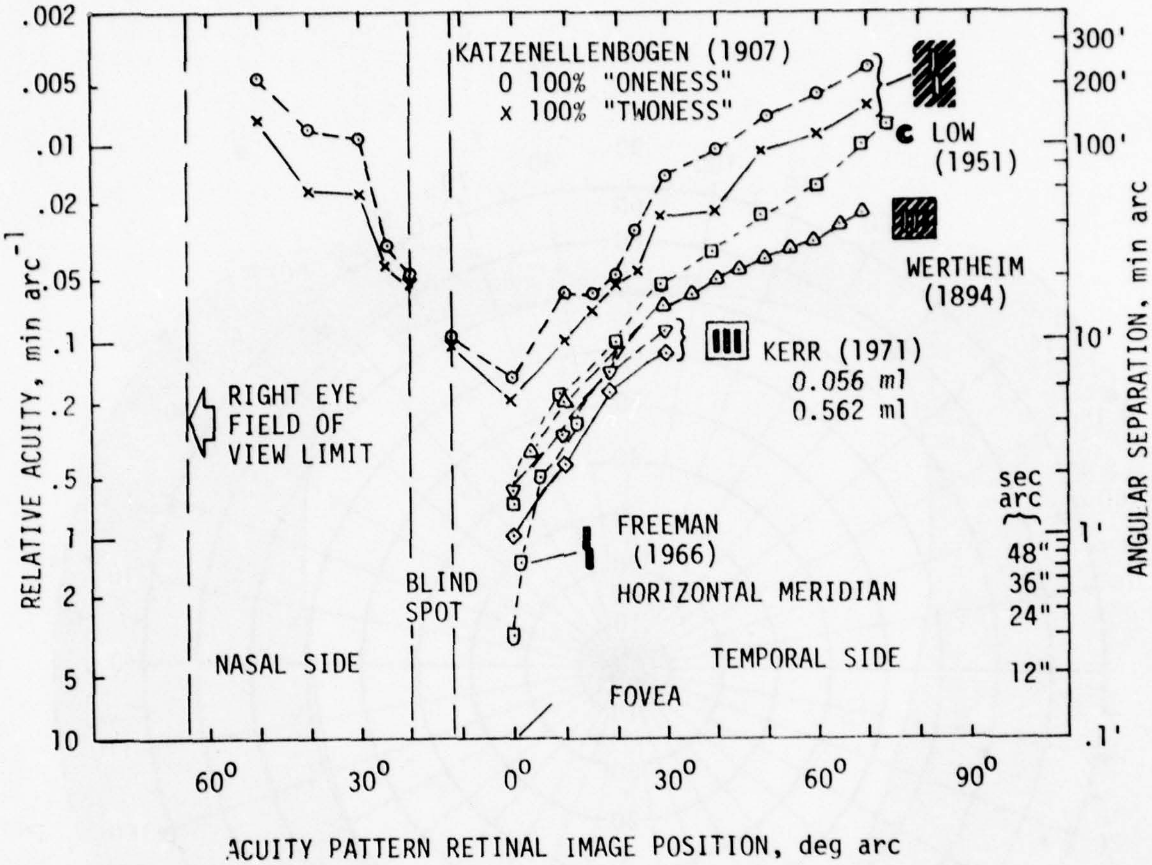

Figure 5-2. Right Monocular Acuity Across the Horizontal Meridian for Various Acuity Test Patterns and Contrasts

5.2.2 Field of View Limitations. The FOV constraints imposed by the aircraft depend upon three factors. The first factor is the actual structure of the aircraft cockpit and canopy, which physically limit the pilot's FOV. This limitation can be seen in Figures 5-3 and 5-4 for the AH-64 helicopter. The second factor is the FOV required by the pilot to perform normal maneuvers typical of the aircraft. For the AAH, prime importance must be placed on providing sufficient FOV for Nap of the Earth (NOE) flights and ground target detection and recognition. Thus the vertical FOV above the horizon is less important than the FOV below the horizon. At the same time, the largest possible available horizontal FOV is needed, to a maximum of 260° for the pilot and 330° for the gunner. For the pilot, a downward-looking FOV is useful in landing maneuvers.

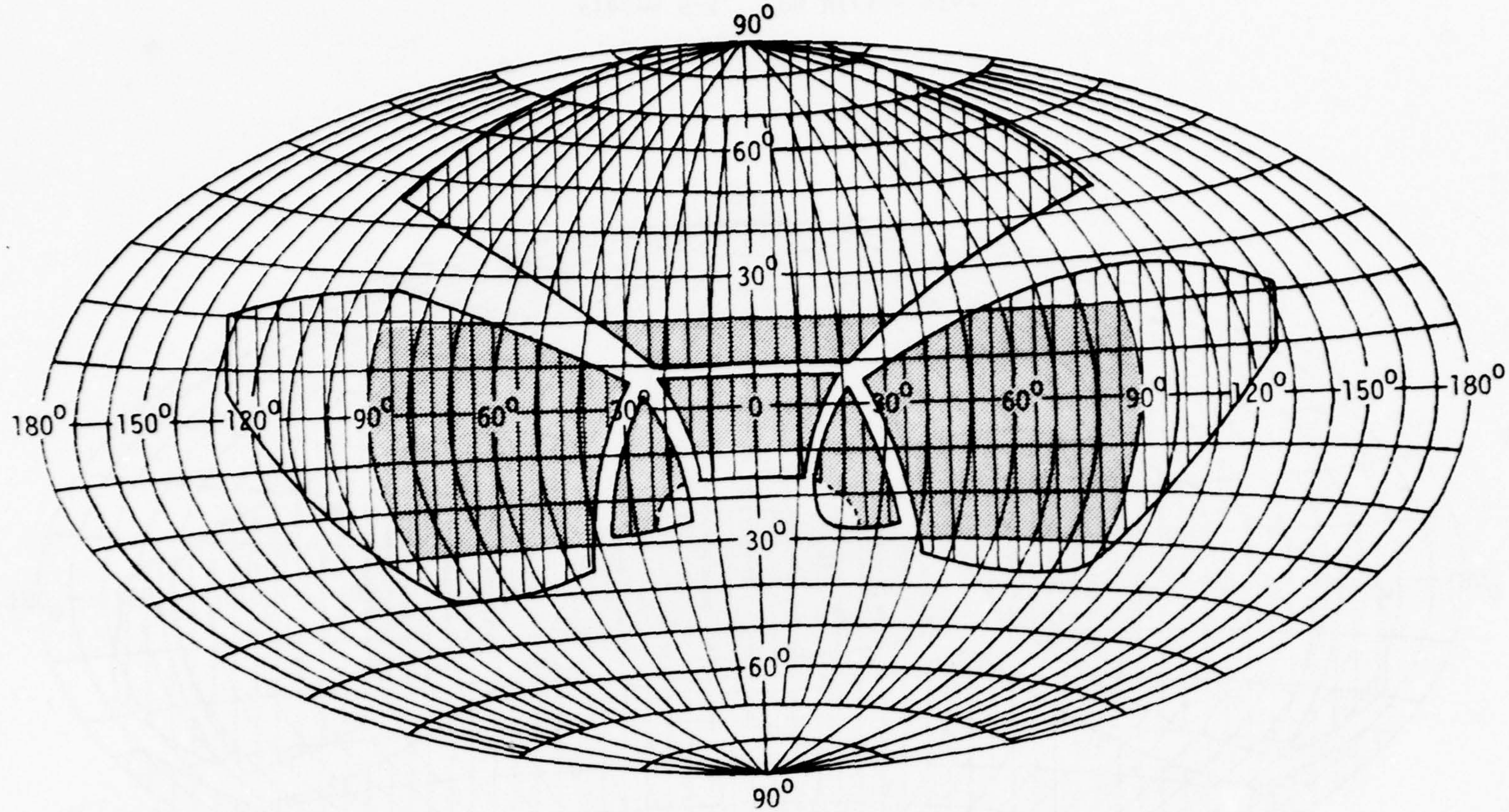

Figure 5-3. Pilot Vision Plot

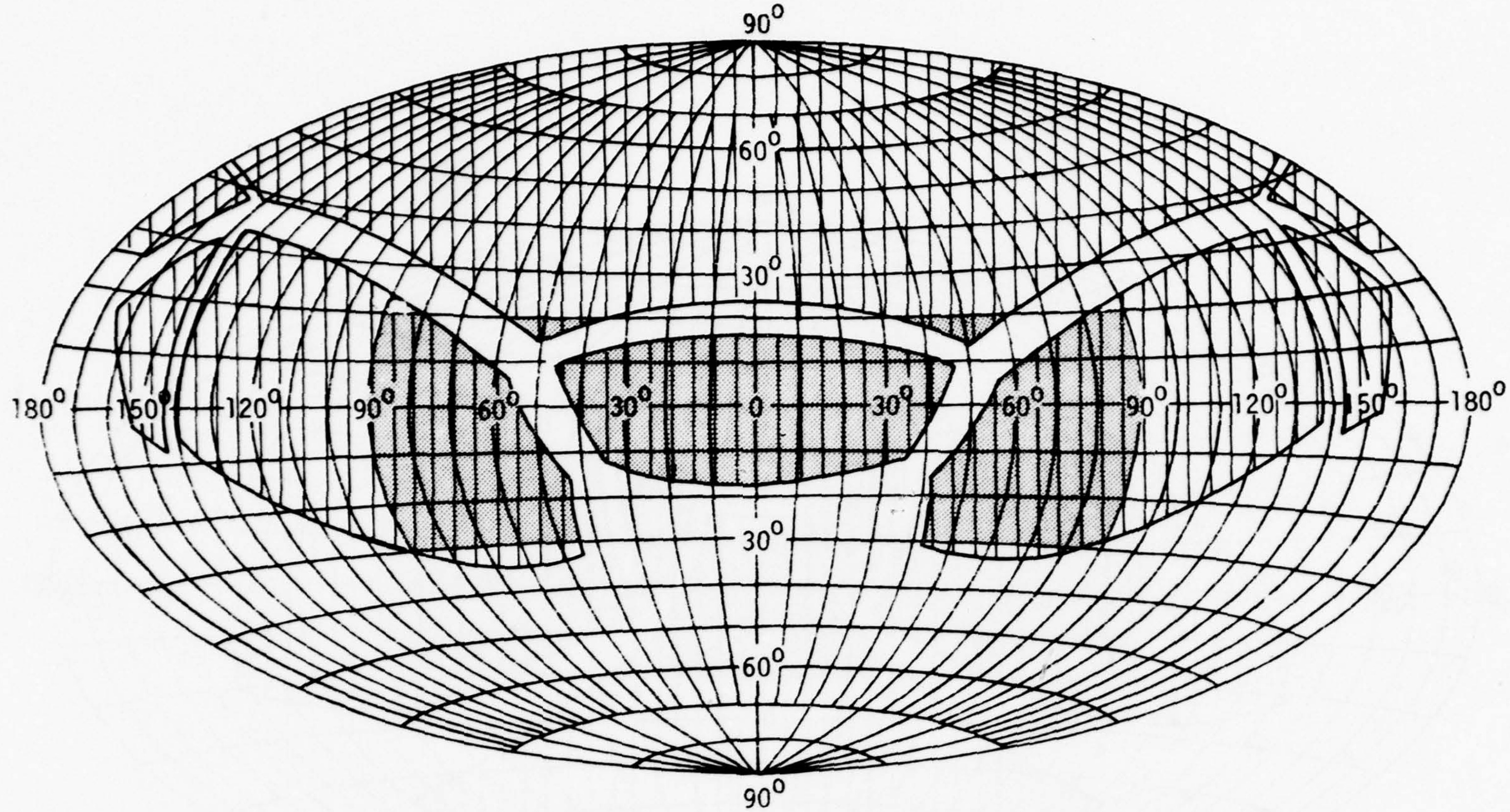

Figure 5-4. CPG Vision Plot

The final constraint on the choice of visual FOV is the technical feasibility of providing the required FOV. From the preceeding discussions, it is apparent that an instantaneous FOV of 210° by 110° within an available display capability of 330° by 130° would be ideal. However, conventional color CRT's and TV projectors are only capable of giving pictures of adequate resolution and brightness when used for FOV's in the order of 50° x 37°. Therefore, it would require 12 display units to provide the instantaneous FOV alone. This is clearly an impractical design.

At the present time, there are several systems under development that might circumvent this problem. These systems employ either a very wide-angle laser scanning projector or a dodecahedron of liquid crystal projectors/trichromatic holographic pancake windows around the simulator. Implementation of either system requires considerable refinement of state-of-the-art techniques, and for this reason they are not likely to provide viable alternatives for at least five years.

In the absence of devices capable of providing the full FOV, it is necessary to consider restricted FOV's as practical alternatives. Based upon considerations of available display devices and display formats and the required mission simulation capability, an FOV of 180° horizontally by 50° vertically provides a reasonable compromise. Such a system may be constructed by using five conventional display units mounted sideways. The horizontal FOV should be adequate for most maneuvers. The vertical FOV, while less than ideal, should provide sufficient scope for most tasks and can be offset to give +20°/-30° coverage or optimum coverage decided by field tests. This FOV is shaded in Figures 5-3, and 5-4.

The final factor in determining the displayed FOV is the ability of the system to provide sufficient information to fill the display. No existing operational probe incorporated in a camera/probe model board system covers more than approximately 140°, and it would prove cumbersome to mount five cameras if a 180° probe did exist. Since the limiting factor in a Computer Generated Image (CGI) system is the number of points or edges that can be computed in the given time interval and since a larger FOV requires more edges to fill it, either the time interval must increase or the number of computed edges per display area decrease. Since the time interval is fixed by the requirement of a smoothly moving scene, the number of points or edges must remain the same. Thus a single CGI system can only provide a detailed scene over a limited FOV. One way around this problem is to use multiple CGI systems to cover a wide field of view. Alternatively, an area of interest technique could be used to obtain a large field of regard.

5.2.3 Area of Interest (AOI). Assuming that no existing system can provide sufficient full color, high-resolution information for a 180° x 50° display area at a reasonable cost, a further compromise is necessary, that of an AOI display. The AOI concept is based on the premise that the pilot is looking at only one portion of the display at any given time. By monitoring the pilot's head position, thus determining at which part of the scene he is looking, it is possible to ensure that the pilot always sees a high-resolution image at that point. Several techniques exist for monitoring pilot head position. In the AH-64, standard helmet-mounted sighting equipment is used; thus this technique is the cheapest and simplest way of monitoring it in the simulator.

The possibility of monitoring eye movement to further refine the system was considered, but present eye monitoring techniques require fixed head positions or the mounting of excessive equipment on the pilot's helmet. Furthermore, the human eye moves in very rapid, semi-random movements (saccadic movement), which make it very difficult to follow.

The AOI technique has been tried on several simulators by Singer, Northrop, and the USAF. In most of these trials, the AOI moved with yaw, pitch and roll of the pilot's head. After having discussed Northrop's experience with Norm Richards and Don Patton of Northrop's Aerosciences Laboratory and having reviewed the literature on several other systems that were experimented with (particularly the USAF ASD SIMSPO project 2235), we find the following points describe the main difficulties with the technique:

(a) With a conventional 37° x 50° FOV, the edges of the AOI field are too apparent. This distracts the pilot and sometimes introduces false attitude cues.

(b) The probe/display movements must be very accurately synchronized so as not to disturb the pilot.

(c) The probe/display movements must be highly responsive, yet stable.

(d) A deadband must be provided so that the picture does not move with small head movement.

(e) The picture pitches annoyingly if the pilot glances briefly at his instruments. Conversely, on landing, the pilot must sometimes assume awkward and unnatural head positions to correctly view the runway prior to touchdown.

(f) The pilot is forced to scan the scene with head movements as opposed to combined head/eye movement. In some cases with small FOV AOI's, the pilot was forced to constantly move his head from side to side to keep from getting disoriented.

It should be mentioned that studies are now underway at Williams Air Force Base to determine optimum AOI FOV and to optimize the head slaving technique as a whole. This research is of a proprietary nature and therefore no information is available.

In response to the above problems, the following solutions are proposed:

(a) The AOI should cover 110^{o} horizontally by 50^{o} vertically. This is equivalent to three conventional displays. This FOV covers essentially the normal overlapping horizontal binocular vision field.

(b) The displayed image could be electronically slewed. The rate would be controlled by the probe slew rate. If, instead, a mechanical system were used, care would be taken to match the servo responses and drive the system with reference to the probe.

(c) With a 110^{o} AOI FOV within a total 180^{o} FOV, a maximum slew rate of about 80^{o}/sec would be required. Present optical probes and CGI systems are capable of such rates.

(d) Based on Northrop's experience, the initial system should have a deadband of about $\pm 5^{o}$.

(e) The AOI should fill the entire vertical FOV (50^{o}) so that no pitch movements would be monitored.

(f) The large instantaneous FOV of the AOI would eliminate the pilot's sense of being forced to move his head to look around. Eye scanning within the FOV is possible. At the same time, the edges of the picture should not distract the pilot nor give false cues, since they are towards the edge of his vision field.

In a CCTV/model board system, a single probe coupled to three CCTV cameras could provide the $110^{o} \times 50^{o}$ AOI input. The remaining 70^{o} out of 180^{o} could not be covered by the probe; however, a CGI system could be used to fill in low-resolution peripheral information based on the model contours stored in the data base. Alternatively, a point source slide projector could be used to provide an overlapping horizon cue. If a pure CGI system were to be used, the remaining 70^{o} could contain low-resolution data based on the CGI terrain data base. Such detail in the peripheral vision field would

enhance motion and attitude cues. Since the acuity of the eye drops off rapidly from the center of the FOV, low-resolution information presented to the peripheral vision field has the appearance of normal detail. The proof of this phenomenon was presented at the 1977 SID conference by Kraiss and Schubert (Ref.5-4).

While no visual detail is required above the 50^{o} vertical FOV, this area could be filled with featureless sky of the same color and brightness as the top of the picture. This would reduce the possible distraction of the top edge of the visual system FOV (which is still within the pilot's total visual field) and would provide a more realistic distribution of illumination within the cockpit, which could be important with respect to other pilot tasks.

The technique which is used could be simply to frost the top of the windows and canopy and to illuminate this area with the correct color and intensity.

5.2.4 Determination of Optimum FOV by use of an Eye Mark Recorder. An analysis of pilot's eye movements was discussed during a visit with Dr. J. Barnes at the U.S. Army Human Engineering Laboratory at the Aberdeen Proving Ground. The reason for the visit was to gather information on target detection, particularly the detection of tanks from helicopters during NOE flying.

Dr. Barnes conducted a study which measured the performance of helicopter observers when looking for camouflaged and pattern painted tanks (Ref.5-5). The results of HELCAT are discussed in paragraph 5.1, but one interesting part of the experiment involved the use of an eye mark recorder to analyze the observer's search patterns. As the operation of the eye mark recorder was explained, it became apparent that such a device was an ideal tool for measuring the required FOV for each specific maneuver of an AH-64. The resulting data would enable the optimum FOV to be established for the simulator. If, as seems likely, the FOV will be determined by cost factors, the experiment would be used to determine the adequacy of the FOV for each maneuver and perhaps how each maneuver should be trained in the simulator.

A similar experiment was actually performed by Dr. Barnes in a previous study, which is discussed in Ref.5-1. An earlier version of the eye mark recorder was used. It weighed over three pounds and required a brace to be worn in the mouth of the pilot. The model 4 Eye Mark Recorder (Figure 5-5), made by NAC and used in the HELCAT study, weighs 13½ ounces and is

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Ref.5-4. Kraiss, K. and Schubert, E., Matching Image Resolution to the Eye Resolution, SID Symposium Proceedings, Boston, 1977.

Ref.5-5. Barnes, J. and Doss, N., Human Engineering Laboratory. Camouflage Applications Test (HELCAT) Observer Performance, U.S. Army HEL Technical Memorandum 32-76, Aberdeen Proving Ground, June 1976.

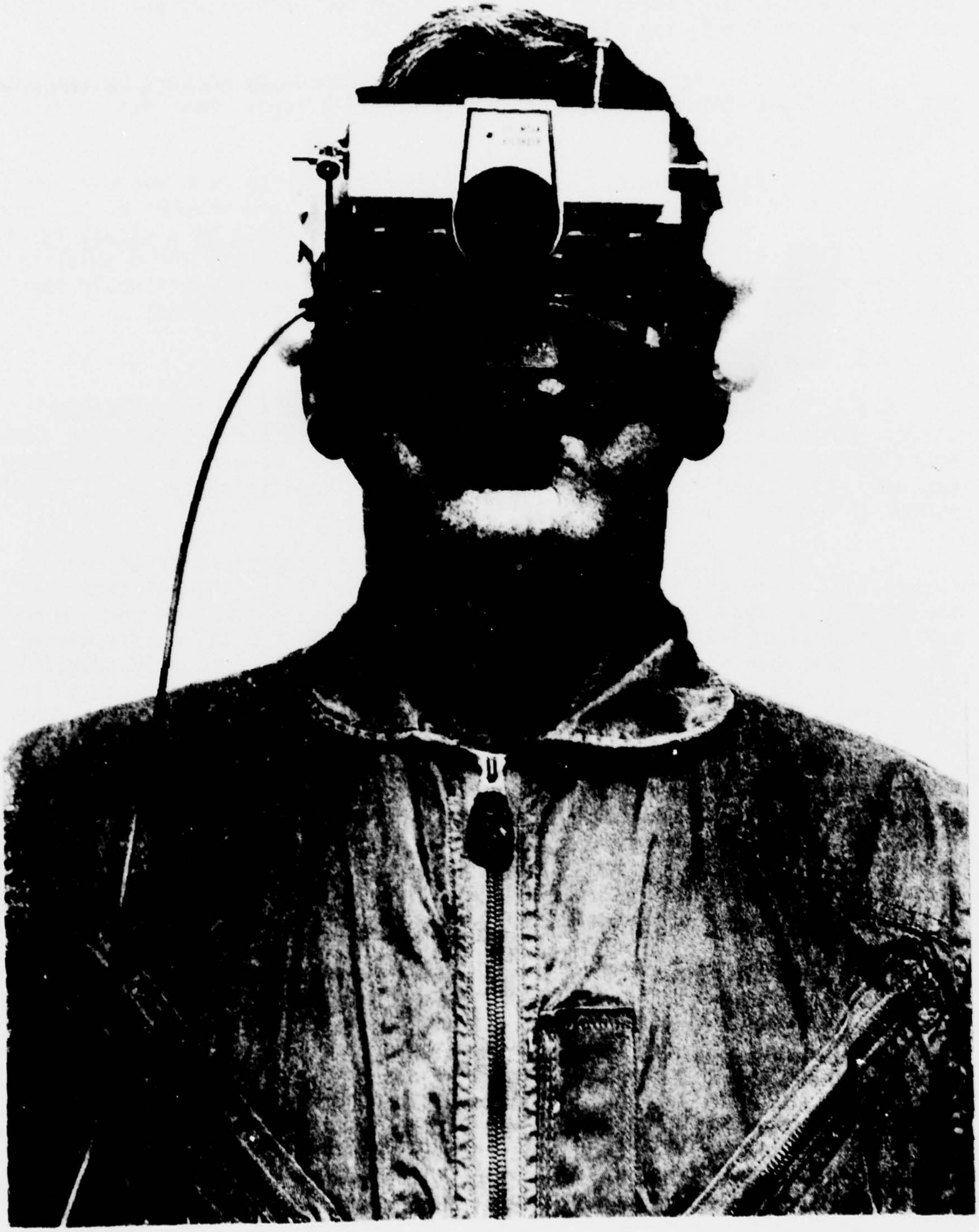


Figure 5-5. Eye Mark Eye Movement Measurement System

similar to a pair of goggles. Dr. Barnes is fitting this device to a helmet that will allow rapid adjustment of the system for each pilot and have minimal interference with the pilot's normal vision.

The U.S. Army Aeromedical Research Laboratory at Fort Rucker also has one of these eye mark recorders, about which a report has been published (Ref.5-6).

The data would not only show required FOV for each maneuver but also give an indication of the pilot's head movement and whether or not the pilot uses any part of the forward structure of the AH-64 as a visual reference. All of this information is critical to the design of the display system and a short study along the lines of Dr. Barnes experiments would seem to be an obvious prerequisite of any major simulator procurement.

5.3 DISPLAY SYSTEMS

5.3.1 General. The display system is the final link in the video chain. No matter how the picture is generated, no matter how high the inherent video resolution, what the pilot ultimately sees depends on the display employed. Thus the specification and design of the display system is a major factor in a simulator study.

The most important parameters of the display are brightness, resolution, contrast, distortion, and color capability. The brightness of the display as seen by the observer pilot must be sufficient to perform normal daylight maneuvers. This does not mean that the display must achieve levels comparable to normal daylight. The human eye is extremely adaptable and can resolve one arc minute in full color for a visible luminance of between about 1 foot-lambert and 10^4 foot-lamberts. Most visual systems such as CAE's CH-47C simulator or the USAF's SAAC, ASPT, or LAMARS simulators operate at brightness levels between 0.5 foot-lambert and 5 foot-lamberts. Within this range there seems to be good pilot acceptance of the display, providing the cockpit environment is appropriately dimmed. Higher brightness levels, when used, have resulted in visible scene flicker, higher apparent noise levels, and degradation of the display resolution due to operation of the display device at or near its limit. Therefore, for the FWS, a brightness level of five foot-lamberts at the display output should prove sufficient.

The resolution of a display device viewed from a fixed distance by a human observer is best described by the minimum resolvable angular element. A human eye under normal lighting conditions (one foot-lambert) has a resolution of about one arc minute. However, present state-of-the-art television systems are limited to resolutions of about 800 TV lines per picture height. For two TV lines to equal one arc minute, the individual display can cover no more than $9^{\circ} \times 7^{\circ}$, clearly a very restricted Field of View (FOV). In fact, for a conventional FOV of 48° by 36°, taking into account all factors, the limiting resolution of an 800-line system is about six arc minutes per TV line pair. Increasing the number of TV lines is

Ref.5-6 . Simmons, R.R., Kimball, K.A., and Diaz, J. J., Measurement of Aviator Visual Performance and Workload During Helicopter Operations, U.S. Army Aeromedical Research Laboratory Fort Rucker, 1977.

extremely difficult and very costly. Furthermore, should a terrain model board/CCTV system be employed, the limiting resolution of an optical probe is three arc minutes. This further degrades system resolution. Thus a display resolution of better than six arc minutes, while desirable, is of little value. In fact, few display devices are themselves capable of better than six arc minutes when used to cover a conventional FOV. Therefore, we shall consider a resolution of six arc minutes as seen from the pilot's eye point to be a reasonable specification for the display.

The scene contrast is a very important factor in picture quality. Limiting resolution is usually given as a criterion for judging displays; however, we have found considerable differences between displays having the same limiting resolution. The most critical parameter for the display is its Modulation Transfer Function (MTF) measured at all spatial frequencies up to the limiting resolution. Although the square shape as shown in Figure 5-6 results in a good crisp picture, the sloping curve gives a soft appearance, even though it has the same limiting resolution. Some display devices have large area contrast ratios of 50:1 or more; however, experience has shown that high image quality is usually obtained with contrast ratios between 10:1 and 20:1, providing the MTF is good.

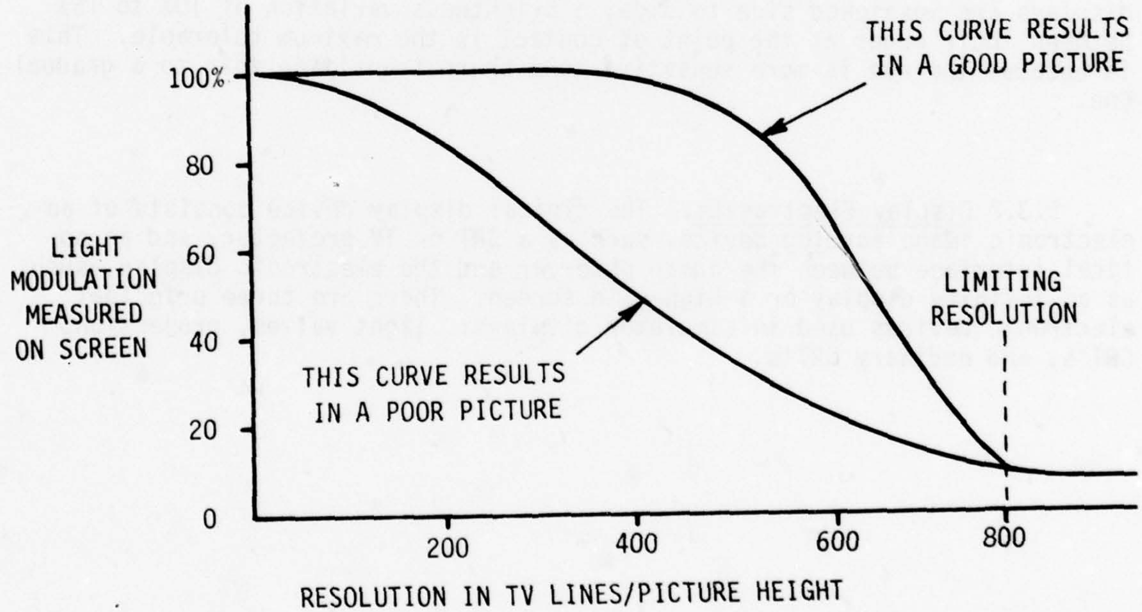


Figure 5-6. Display MTF Curves

Distortion in a optical system can generally be reduced to less than 1%, but for a TV system a maximum distortion of 5% is normally tolerated. At this level, the observer cannot detect the distortion unless a specific test pattern is displayed. However, if mosaics of display devices are used, distortion becomes more evident at edge joints. Thus the minimum possible distortion is recommended. Most existing high-resolution TV displays are capable of between 1.5% and 2% distortion. Thus a practical specification of 2% distortion at the display output will be adopted.

The final requirement is for a full color display. Several studies have been conducted to determine whether color is necessary for visual simulation in pilot training (Ref.5-7), but few conclusive results have emerged. The only consistent factor has been a pilot preference for full color. However, color is necessary to properly train for tactics in a real-world environment, simulate target detection, and simulate threat or friendly weapons fire. Navigation in a nap-of-the-earth environment also requires a color display. We shall, therefore, consider a color display as mandatory and specify that it should meet NTSC color standards.

Another important consideration is that of the uniformity of display brightness. For a single display device, a center-to-edge brightness variation of 50% is usually considered acceptable. However, if two or more displays are mosaicked side to side, a brightness variation of 10% to 15% between their edges at the point of contact is the maximum tolerable. This is because the eye is more sensitive to a sharp transition than to a gradual one.

5.3.2 Display Electronics. The typical display device consists of an electronic image forming device, such as a CRT or TV projector, and an optical interface between the human observer and the electronic display, such as an infinity display or a high-gain screen. There are three principal electronic devices used in simulator displays: light valves, projection CRT's, and ordinary CRT's.

Ref. 5-7. Chase, W., Effect of Color on Pilot Performance and Transfer Functions Using a Full-Spectrum, Calligraphic, Color Display System, AIAA Visual and Motion Simulation Conference, Dayton, 1976.

5.3.2.1 Light Valves. A light valve is a large-area television projector that works by electro-optically modulating a beam of light from an arc lamp to produce a real-time projected picture. There are three high-quality light valves currently being manufactured or developed. These are the Eidophor, the General Electric Light Valve, and the Hughes Liquid Crystal Light Valve.

5.3.2.1.1 Eidophor. The Eidophor is the original light-valve projector. The simultaneous color version offers high resolution (800 TV lines), very high light output (2000 lumens), low distortion, and full color capability. Its disadvantages are its large size and weight (2000 pounds) and a requirement for service at about 50-hour intervals. A field-sequential version has been produced which offers similar resolution, high output (900 lumens), and full color capability in a smaller package (700 pounds). This version is available on special order only. The Eidophor's size and weight make it unsuitable for use in a multichannel system.

5.3.2.1.2 General Electric Light Valve. The General Electric light valve is a well proven device offering high resolution (800 TV lines), adequate light output (250 lumens), low distortion, and full color capability. It has the further advantage of small size and weight (125 pounds), making it ideal for use in multichannel displays. A monochrome version is available which GE believes could be converted to a field-sequential mode color projector if required. This device offers excellent registration for a simultaneous system because the simultaneous color version operates by modulating a color diffraction pattern on top of the raster pattern on the control oil layer. However, because of limitations on the modulation of the control layer, it is not possible to maintain the same resolution for all three colors. In fact, the 800-TV-line resolution refers to the green field, the red and blue fields being of somewhat poorer resolution. One way around this limitation is to use the field-sequential technique with a monochrome version of the light valve. Here, registration is perfect and resolution is uniform for all three primaries. The light output should equal or exceed that of the simultaneous version.

5.3.2.1.3 Hughes Liquid Crystal Light Valve. The Hughes liquid crystal light valve is the first of a new generation of light valves that operate by using liquid crystal phenomena. Here, light is controlled by varying its degree of polarization, using the twisted-nematic effect of the liquid crystal. Although several companies are experimenting with these devices for display applications, Hughes is the first, to our knowledge, to produce real-time video displays using this technique. We visited Hughes to see a demonstration of their monochrome prototype (HDP 800), and were given a thorough description of the system by Dr. P. Baron, Senior Scientist. We also attended a presentation of papers on the color prototype given at the 1977 S.I.D. Symposium. At present, only the monochrome version is available; however, a color prototype is operational and research is continuing under strong support from the USAF and USN. The design goal for the color projector

is for a high-resolution (1000 TV line), adequate light output (220 lumens polarized), very low distortion (0.5%), full color device of small size and weight (300 pounds) and high reliability. When these goals are met the projector will become an excellent choice for many simulation displays. The present plan is to produce this projector by 1980. However, there are numerous engineering problems to be solved, some as basic as the limitations imposed by the physics of the liquid crystal unit itself. In particular, the response speed of the liquid crystal is marginal. Therefore, it is our opinion that the color projector may not be perfected until the early to mid-1980's and for that reason we shall not consider it a contender for the FWS display device at this time.

5.3.2.2. Projection CRT's. Projection CRT's are very high output CRT's used in conjunction with reflective or refractive optics to project TV pictures. Since they operate at very high powers and voltages, they often require special cooling and radiation shielding. Projection CRT's are exclusively monochrome. Full color displays employ three CRT's or a field-sequential system. Two high-resolution systems are discussed: the Aeronutronic Ford Simultaneous Projector and the Grumman Field-Sequential Projector.

5.3.2.2.1. Aeronutronic Ford TV Projector. This projector is available in two versions: a three-CRT system and a six-CRT system. Both provide 1000 TV lines resolution with low distortion. The basic three CRT system provides an output of 1000 lumens and weighs 700 pounds for the head and 600 pounds for the power supply. The six-CRT system provides an output of 2000 lumens and weighs twice as much. Both models suffer from the same limitations, such as excessive size and weight and registration difficulties, particularly for short throw distances. This system is unsuitable for a multichannel display.

5.3.2.2.2. Grumman Field-Sequential TV Projector. This projector is being developed by Grumman for use in closed circuit field-sequential TV systems. It employs one high-power, high-resolution projection CRT and a color wheel to provide a high-resolution, moderate output, low-distortion, compact system. The prototype of this device should be operational shortly. Preliminary data indicates that this projector will be ideal for multichannel field-sequential systems. Further discussion must await operation of the prototype.

5.3.2.3 Conventional CRT's. The conventional color CRT is the most common color display in use today. There are two basic types, one the three-gun shadow mask tube, the other the beam penetration tube.

5.3.2.3.1 Shadow Mask Tube. The conventional shadow mask tube employs triads of red, blue, and green dots that are excited by three separate electron guns. A shadow mask is incorporated into the tube to permit only one gun of the three to excite only one color of the triad. These tubes are presently available in sizes up to 26 inches, although some larger experimental versions have been produced. They are capable of faceplate brightnesses as high as 100 foot-lamberts. The limiting resolution of these

tubes depends upon the number of triads of dots or bars in a linear dimension of the tube. These triads exhibit a quantizing effect on the displayed information.

Several high-resolution tubes are available. RCA produces a 700-line resolution tube with 50 foot-lamberts of brightness, and Matsushita produces a tube capable of 900 TV line resolution at about the same brightness. Both of these tubes are suitable for a high-quality display but are limited by their lack of brightness. Higher brightness CRT's are of lower resolution, typically 650 TV lines.

5.3.2.3.2 Beam Penetration CRT's. Beam penetration CRT's work on a principle entirely different from that of shadow mask CRT's. In the beam penetration CRT, different transparent color phosphors are arranged in layers on the inner surface of the tube. An electron beam excites a particular color by varying its penetration depth into the phosphor layer sandwich. This is done by varying the high voltage across the tube, typically between 7 and 15 kV. Since the phosphor is a continuous layer, resolutions comparable to high-quality monochrome systems are possible. However, at present it is only possible to layer two color phosphors on top of one another, typically red and green. This makes it impossible to generate full color pictures in this system. Furthermore, heat dissipation within the phosphor layers is less efficient than with a single layer, as in a shadow mask tube. Thus beam penetration systems are only capable of about 15 foot-lamberts of brightness at present. This relatively low brightness level, coupled with the inability to display full color images, renders the beam penetration CRT unsuitable for use in the FWS display system.

5.3.2.4 Summary of Display Electronics. The requirement for the FWS display driver is for a compact high-brightness, high-resolution device, small enough to be used in a multichannel display on a motion base. Among the projection devices discussed only the General Electric light valve and the Grumman field-sequential projector fulfill these criteria. Both the Eidophor and the Ford projectors are too large and heavy to consider, and the Hughes liquid crystal light valve is not sufficiently developed. The General Electric color light valve is then the only projection device capable of simultaneous mode operation. Either the G.E. or the Grumman projector can be used in a field-sequential mode; however, modifications to the light valve will require a development program. The Grumman projector should be considerably simpler and cheaper than a modified light valve, but we must await a demonstration of the prototype before considering it further.

The shadow mask CRT's offer an alternative display but of both lower brightness and overall resolution. The shadow mask dot pattern is the limiting factor, since larger dots are brighter, but resolution is degraded accordingly. These devices are considerable cheaper than projection televisors.

5.3.3. Optical Display Components. The picture generated by an electronic display can be viewed in one of three ways: directly, by projection on a screen, or through an optical system. A direct view is limited to CRT s, and these are generally too small for out-of-the-window displays. To provide any reasonable angular coverage, the CRT must be positioned very close to the pilot, and the pilot is then very conscious of viewing a television picture. Furthermore, the pilot must focus his eyes quite closely in front of himself and this can cause eyestrain. Thus the only suitable viewing devices are projection screens and optical systems.

5.3.3.1 Projection Screens. Projection screens are suitable for use with light valves and CRT projectors. They can take two basic forms.

The first is a large flat screen placed at a moderate distance in front of the pilot, say 10 to 15 feet. This will suffice for small viewing angles, but for large angles the screen size becomes unwieldy. To cover 110^{o} horizontally at 10 feet requires a 30 foot wide screen. Small screens placed close to the pilot suffer the same disadvantage as direct view CRT's.

The second type of screen display uses a dome, or section of a dome centered about the pilot's eye point. A dome of 10-foot radius can be made to cover fields of view greater than 180^{o} without becoming unwieldy. A pilot-eye-to-screen distance of 10 feet gives a greater sense of depth to the display and eystrain is not a problem. The difficulty in using a dome system stems from the problem of projector placement. The projection point must be as close to the pilot's eye point as possible so as not to introduce distortion or incorrect perspective cues to the pilot. In practice, this distance is determined by projector size and aircraft configuration and is usually at least 2 feet. At the same time, the picture is being projected onto a curved surface, so that special optics must be used to correct for the resulting distortion. Wide-angle displays require several projectors, and it is often difficult to fit these within the constraints of the dome.

An advantage is using projection screens is that the screen 'gain' can be varied. Instead of using a perfect diffuser, or unity gain screen, a screen can be designed to concentrate the light reflected off it into a narrow solid angle centered about the viewer's eye point. This has the effect of increasing image brightness and reducing the effect of background lighting on the scene contrast. Gains as high as 17 are possible, but for normal FOV, gains from 1 to 8 are generally used. Gains higher than 8 suffer from rapid brightness fall-off with increasing viewing angle.

The most serious disadvantage of dome projection screens is the proximity of the screen surface. When the pilot moves his head, it is readily apparent that the displayed scene is only a flat projection. This is due primarily to the lack of parallax cue in the picture, which should change with head movement as shown in Figure 5-7. However, in the AH-64 the pilot's head position is monitored by the helmet sighting system, so that it is

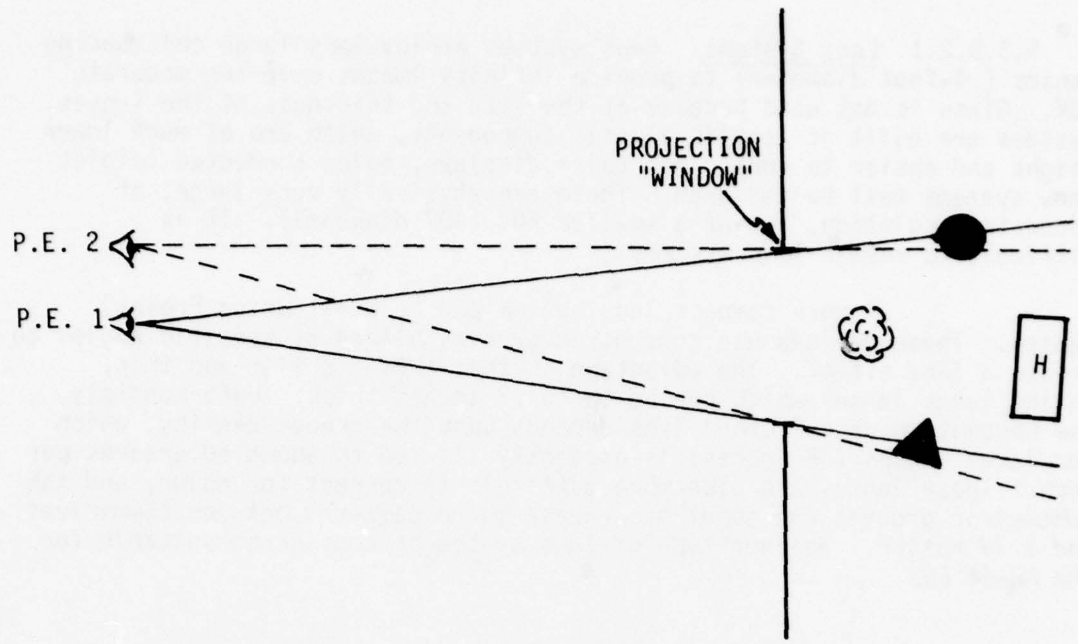


Figure 5-7. Effect of Head Movement on Perceived Scene

possible to correct this deficiency of the display system.

If a CGI system were used, the change in pilot's head position could be used to change the effective pilot eye point in the 'window' calculation. The processor would then transform the scene data to produce a displayed image exhibiting correct parallax under all conditions. If a model board/CCTV system were employed, a correction could be applied to the probe position and orientation to generate approximately the correct effect. However, since the model board system can only simulate the change in pilot eye look point without taking into account the resulting change in display 'window', a small error will be apparent at the edges of the scene. This should not prove troublesome since the parallax cue will be correct over most of the visible scene.

5.3.3.2 Optical Systems. Optical display devices are used for two purposes. First, by magnifying a small high-resolution pircture such as on a CRT they can provide wide viewing angles from small electronic displays. Second, by varying the focal length of the system they can place the plane of the display at any apparant distance from closeup to infinity. By placing the plane of the image at infinity, eyestrain becomes negligible and the lack of three-dimensional parallax cues is not apparent. The systems used are of three types: lenses, classical mirror infinity displays, and Farrand pancake windows.

5.3.3.2.1 Lens Systems. Lens systems employ very large collimating lenses (4-foot diameter) to provide infinity images covering moderate FOV. Glass is not used because of the size and thickness of the lenses. Systems are built of acrylic plastic components, which are of much lower weight and easier to work. For color displays, color corrected triplet lens systems must be designed. These are physically very large, of adequate resolution, but of a smaller FOV (40° diagonal). It is difficult to mosaic lens systems.

A more compact lens system can be built using Fresnel lenses. These devices use concentric grooves blazed at specific angles to create a lens effect. The advantage is that they are flat and thin, unlike large lenses which can be up to 12 inches thick. Unfortunately, the resolution of a Fresnel lens depends upon the groove density, which for large lenses (48 inches) is presently limited to about 50 grooves per inch. These lenses are also more difficult to correct for color, and the concentric grooves can sometimes create moire patterns between themselves and a TV raster. Neither type of lens system is considered suitable for the AH-64 FWS.

5.3.3.2.2 Classical Mirror Infinity Display. A good solution to the problem of displaying collimated wide-angle FOV is provided by the classical infinity display. This system uses a mirror as the active optical element, resulting in high resolution and no color aberration. The image from a CRT or a rear projection screen is reflected onto the mirror via a 45° beamsplitter. The resultant collimated image is viewed on axis through the beamsplitter. FOV's up to about 55° horizontally are possible, the limitation arising from the interference of the beamsplitter with the mirror. Although these systems are physically bulky, they can be mosaicked to give a wide FOV. The efficiency of the system is about 20%. These displays are of moderate cost.

5.3.3.2.3 Farrand Pancake Windows. The best method for obtaining a wide field infinity display is to use a mosaic of pancake windows. These devices are in-line versions of the classical infinity display, using a birefringence technique to permit a thin sandwich of in-line elements. They offer physically compact, color corrected, high-resolution displays capable of individually covering FOV's up to an 80° diagonal. They have two main disadvantages. First, they are optically very inefficient, exhibiting a transmission of about 1%. Thus they must be used with color projection devices, not CRT's. Secondly, they are very expensive, especially the larger sizes. Under certain conditions such as night lighting, they can exhibit ghosting. However, their advantages of compactness and wide FOV generally more than compensate for the added expense of using them.

At present, Farrant Optical Co. is engaged in a project to construct a holographic version of their trichromatic (full color) pancake window.

The goal of this program is to provide a holographic analog of the pancake window on a large photographic plate that can be easily and cheaply reproduced. If this is accomplished, the cost of producing pancake window displays should be markedly reduced. Present estimates are to have a working model by the early 1980's.

5.3.4 Display Systems. From the preceeding discussion it is apparent that we are left with three possible electronic display devices: the GE light valve, the Grumman field-sequential CRT projector, and the high-resolution shadow mask CRT, and three possible optical displays: the dome screen, the Classical Infinity Display (CID), and the Farrand pancake window. For the forward field of view in the AH-64, we will require a wide-angle display, say 180^o by 50^o, which can only be produced by a mosaic of conventional devices. We shall now discuss several possible systems.

5.3.4.1 Display Using Classical Infinity Displays. The CID can be used with any of the electronic display devices, directly with a CRT or with a projector and rear projection screen. Assuming a transmission of 20% and a CRT brightness of 50 foot-lamberts, a CRT/CID system is capable of 10 foot lamberts of output brightness. This is comfortably more than our 5 foot-lambert requirement. A projection device such as the GE light valve used with a 26-inch diagonal screen and a CID would produce on output brightness of 20 foot-lamberts. Since only 5 foot-lamberts are required, a CRT is the better choice for the system. It is cheaper than a projector and is considerably more compact. In fact, since we must make a mosaic of displays to cover the desired FOV, projectors would complicate the design considerably. A high-resolution CRT is capable of meeting all the other performance requirements of the FWS display.

To cover 180^o by 50^o would seem quite simple using five displays, each 50^o by 37^o, but CID's cannot be mosaicked that easily because of their size and the position of the driving CRT's.

To cover the desired FOV will require a minimum of ten displays. Again, because of their physical size and structure, it will be impossible to abut the display properly. A gap will be evident between individual units, but this may have the advantage of reducing the apparent brightness variation between displays. A possible CRT/CID display layout is shown in Figure 5-8. This layout may interfere with the instrument panels. The CRT/CID approach is likely to provide adequate results at moderate cost, the main disadvantage being the large number of channels required.

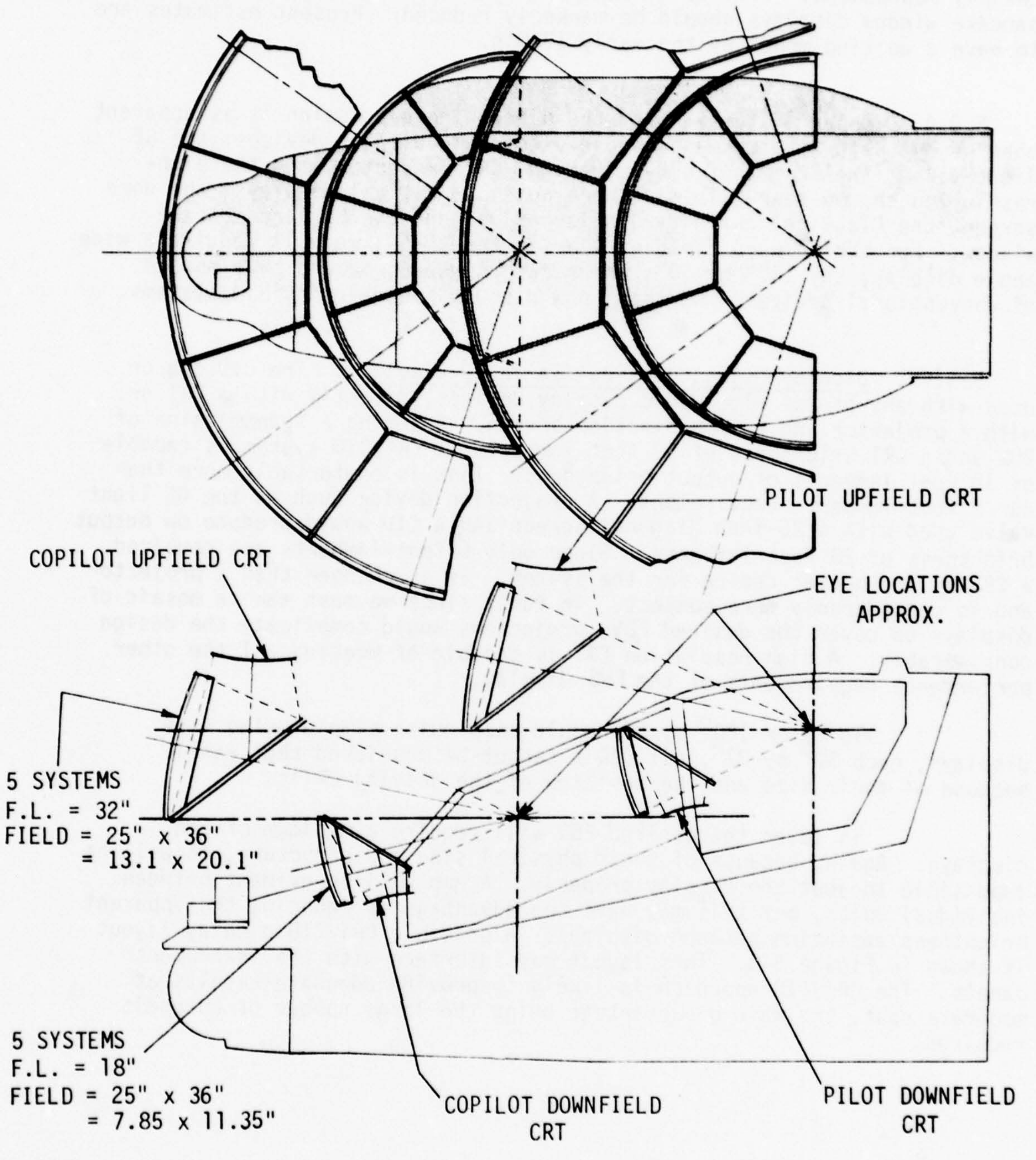


Figure 5-8. CRT/Classical Infinity Display Layout

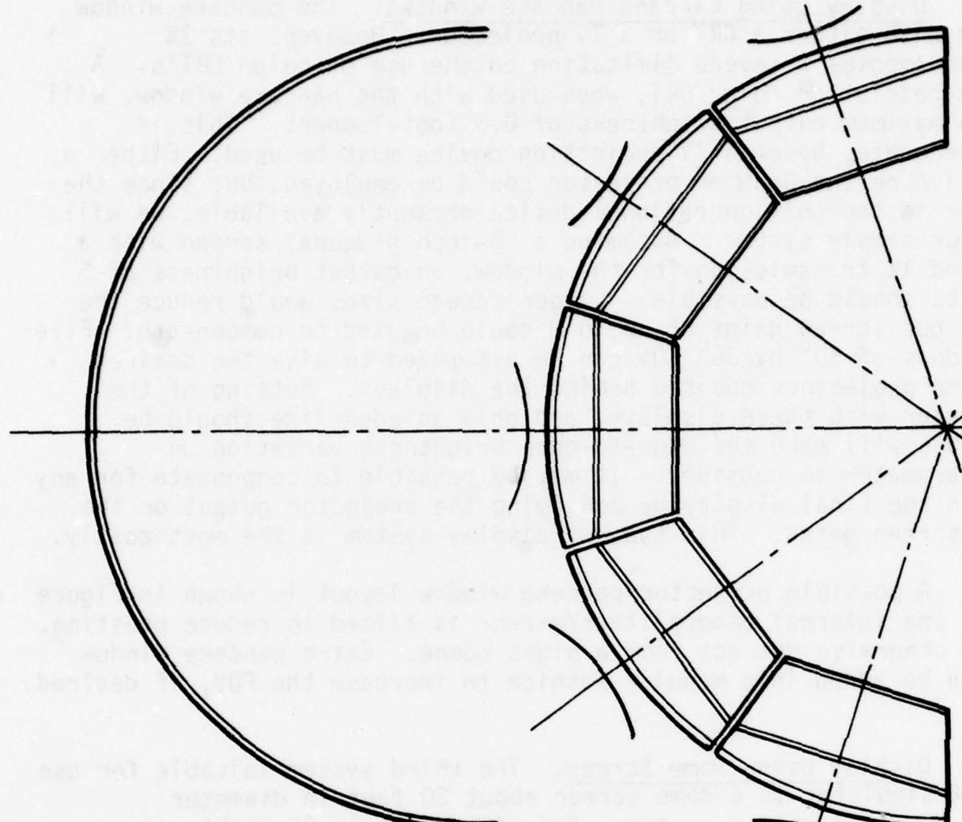
5.3.4.2 <u>Display Using Farrand Pancake Windows</u>. The pancake window may be used with either a CRT or a TV projector. However, its 1% transmission imposes a severe limitation on the use of color CRT's. A normal high-resolution color CRT, when used with the pancake window, will result in a maximum output brightness of 0.5 foot-lambert. This is clearly inadequate, hence a TV projection device must be used. Either a GE light valve or the Grumman projector could be employed, but since the GE projector is the only operational device presently available, we will use it in our sample system. Assuming a 26-inch diagonal screen with a gain of 5 and 1% transmission for the window, an output brightness of 5 foot-lamberts should be possible. Larger screen sizes would reduce the brightness, but screen gains of up to 8 could be used to compensate. Five pancake windows of 50^{o} by 36^{o} FOV can be assembled to give the desired FOV, with the projectors mounted behind the displays. Butting of the edges is easier with these displays, and only an edge line should be visible. This will make the edge-to-edge brightness variation an important parameter to consider. It may be possible to compensate for any variation in the final display by modifying the projector output or the projection screen gains. This type of display system is the most costly.

A possible projector/pancake window layout is shown in Figure 5-9. Here, the internal beamsplitter/mirror is tilted to reduce ghosting, which could otherwise detract from a night scene. Extra pancake window displays can be added in a modular fashion to increase the FOV, if desired.

5.3.4.3 <u>Display Using Dome Screen</u>. The third system suitable for use on the AH-64 simulator is a dome screen about 20 feet in diameter illuminated by a projection system. Assuming multiple GE light values, each covering $50^{o} \times 37^{o}$ at 12 feet from the projector, and with a screen gain of 2, the resultant picture brightness would be 6 foot-lamberts.

The $180^{o} \times 50^{o}$ field of view can be accommodated in either of two ways in a dome/projection system, as shown in Figure 5-10.

(a) Five separate projectors, each covering $50^{o} \times 37^{o}$, can be used. The projectors must be mounted in a group above and behind the pilot's head. As the screen can be made continuous and the projectors can overlap pictures, the effect of the joins can be minimized. The variation in brightness over the FOV must, however, be carefully regulated so as not to be objectionable. Furthermore, since we are projecting onto a dome and from a slightly oblique angle, the projection optics must be modified to correct for distortion and keystoning. This can be done but will increase the cost of the projectors. Mounting the five projectors may be difficult on a small cab.



PANCAKE WINDOW CHARACTERISTICS

EFL = 23.5"
FIELD = 50°V x 36°H
CRT FORMAT = 20.5 x 15.8"

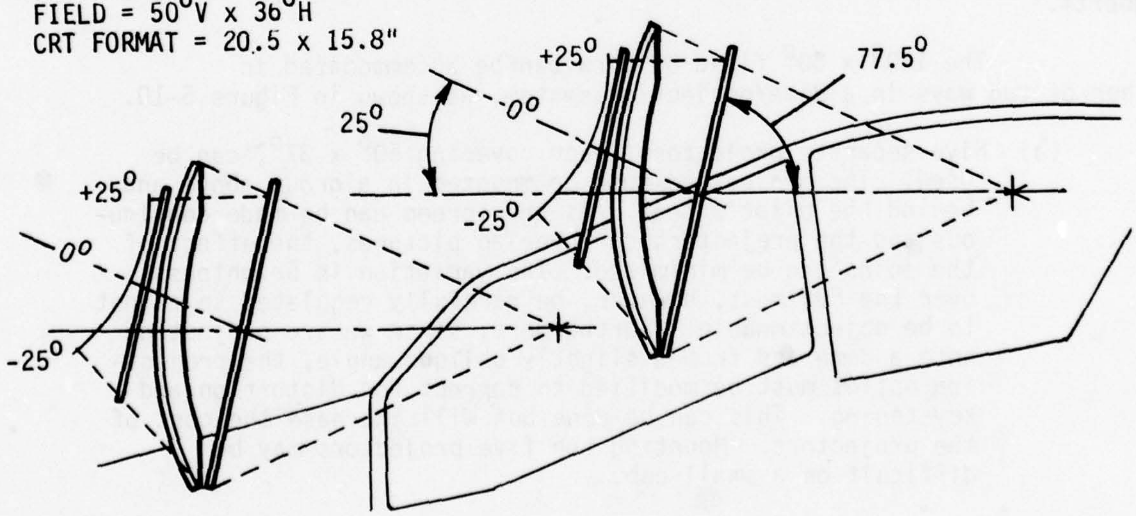
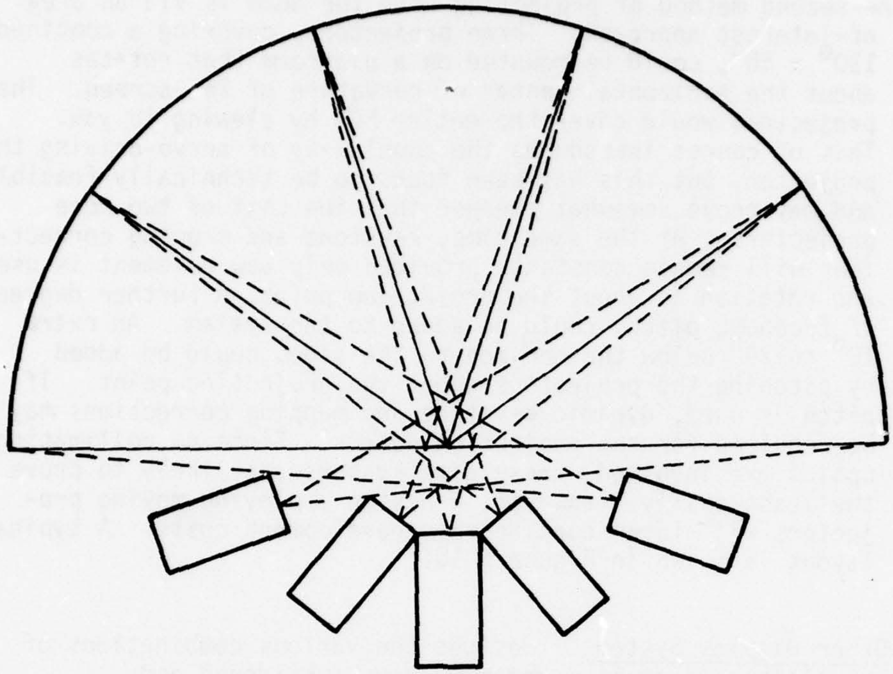


Figure 5-9 Pancake Window Display Layout



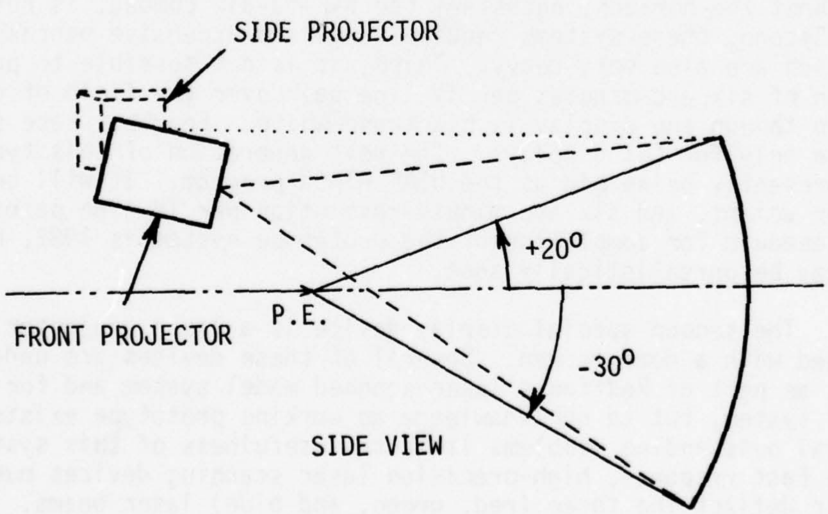


Figure 5-10 Typical Dome with Five Projectors

(b) The second method of projecting onto the dome is via an area-of-interest approach. Three projectors, covering a combined $110^{\circ} \times 50^{\circ}$, could be mounted on a platform that rotates about the horizontal center of curvature of the screen. The projectors would cover the entire FOV by slewing in yaw. This of course introduces the complexity of servo-driving the projector, but this has been found to be technically feasible and may prove somewhat cheaper than the cost of two more projectors. At the same time, keystone and mapping corrections will remain constant, provided only yaw movement is used and rotation is about the projection point. A further degree of freedom, pitch, could be added to the system. An extra 10° to 20° below the horizon to the sides could be added by pitching the projectors about the projection point. If pitch is used, dynamic keystone and mapping corrections may be required for the projection optics. Since no collimating optics are involved, these dome systems are likely to prove the least costly. However, a design employing moving projectors will incur considerable development costs. A typical layout is shown in Figure 5-10.

5.3.4.4 Other Display Systems. Besides the various combinations of lenses and other electronic devices which we have considered and discarded, several other special displays were studied.

The first of these is a dodecahedron of large pancake windows, such as used on the ASPT and SAAC simulators of the USAF. These have the advantage of covering a very wide FOV. There are, however, certain drawbacks. First, the AH-64 is a ground attack helicopter, so that a large FOV about the horizon, necessary for air-to-air combat, is not required. Second, these systems require large and expensive pancake windows, which are also very heavy. Third, it is not possible to provide a resolution of six arc minutes per TV line pair over the field of each window, even though the display is black-and-white. Fourth, these systems are suitable only for CGI displays. The next generation of this type of system is presently being bid as the USAF ATACS program. It will be full color, lower weight, and six arc minute resolution per TV line pair. The tentative schedule for completion of the prototype system is 1981, but we feel this may be unrealistically soon.

The second special display device is a laser projector that could be used with a dome screen. Several of these devices are under development as part of Redifon's laser scanned model system and for NTEC's periapollar system, but to our knowledge no working prototype exists as yet. Several outstanding problems limit the usefulness of this system. First, very fast response, high-precision laser scanning devices must be perfected to deflect the three (red, green, and blue) laser beams. Second, power levels required in the laser spot are somewhat high, requiring protective enclosures around all equipment. Third, laser 'speckle' poses a problem since it produces a degradation of contrast.

Fourth, it is difficult to produce a full color display, i.e., true white is not yet attainable. Finally, these devices are likely to prove quite expensive and would not seem to offer significant improvements in resolution. However, final judgment must be reserved until a working system is available for study.

Finally, while studying Area of Interest (AOI) systems, it occurred to us that a system could be built in which the display is attached to the helmet, and no large area display used at all. The display could be provided via an optical system such as that used in the tactical Helmet-Mounted Display (HMD), only covering a wider FOV and in color. The input could be via a fiber optic cable from an external display device. The mass of the system would have to be kept low to allow free and comfortable head movement, but holographic optical systems of negligible weight could be used. Provision would have to be made for the pilot to view his instruments. This is an area requiring further study.

5.3.4.5 Summary of Display Systems. The preferred approaches are either the dome screen system or the array of five Farrand pancake windows. Both systems have specific advantages and disadvantages, and these will now be summarized.

The dome screen is a cheap, lightweight system offering a continuous display. It can be used with five fixed projectors or three moving ones. The moving projectors would require some development work, but would be easier to use in an AOI mode with a terrain model board and offer the possibility of increased vertical FOV at low cost. The design of projector servos, if used, and correction of the projector mapping function to accommodate a dome display are the major drawbacks of the system. The lack of collimation can be compensated for by referencing the displayed image to the actual head position of the observer.

The Farrand pancake window system offers the advantages of a collimated display in a small package. When used with TV projectors, adequate brightness is obtained, and large collimated displays can be built from arrays of windows. Since the display is collimated, there is no false parallax cue with head movement. However, a detailed study of this proposed system has shown that a 30% increase in the projected field of view for each window is required to allow for a 9-inch head movement. A 6-inch head movement would require a 20% increase in projected field of view, resulting in a corresponding decrease in the resolution. These figures were arrived at even after the inclusion of a new approach to mosaicking pancake windows, in which it is possible to view the screen of each pancake window through the birefringent beamsplitter of the adjacent window.

It would appear that of the two possible systems the dome will offer a higher quality picture at significantly lower cost.

5.3.5 Avionics/Tactical Displays. The AH-64 helicopter and pilot helmet incorporate several state-of-the-art video avionic and tactical displays. Both pilots have a black-and-white helmet-mounted display showing tactical information, FLIR imagery, and TADS imagery. In addition, the copilot/gunner has a TADS system with both video displays and direct optic sighting devices, and an avionics display for status readouts.

The easiest and most realistic way to simulate these systems is to use the real aircraft equipment in the simulator. The display inputs can either be line and scan rate compatible with the genuine equipment, or scan conversion devices can be used to make them so.

The only aspect that requires special attention is the direct view sight. This provides the copilot/gunner with a very high-resolution, full color image with a magnification up to 18 X. The best way to simulate this is to use a high-resolution CRT monitor, since brightness is not a problem and the CRT will be viewed through eyepiece optics that can collimate the displayed image. Resolution of up to 900 TV lines is possible, corresponding to about six arc minutes per TV line pair over a 40° horizontal field. However, direct view display resolution will be much better in the AH-64. In fact, the copilot/gunner would expect to see a significant improvement in resolution when changing from the TADS TV display to the direct optics. While the addition of color will provide a subjective improvement in picture quality over the black-and-white TADS TV, it may be necessary to further exaggerate the difference in quality between the two systems. One possibility is to purposely degrade the TADS TV image, so that the direct view becomes significantly higher in resolution. Unfortunately, this will also degrade target detection task performance unless the targets are depicted oversize to compensate. Another possibility is to superimpose very high-resolution imagery of targets ($\approx$ one arc minute) onto the color CRT background. Since it seems likely that the system will be computer generated, it will be possible to black out the area covered by the superimposed target so as to prevent interference between the two images. This can only be done for a limited number of targets at one time.

5.4 NIGHT OPERATION

5.4.1 Capability of AH-64 at Night. Operation of the AH-64 at night is an important mission requirement, since it is an obvious advantage to be able to engage and destroy the enemy without being seen. The AH-64 is well equipped to operate at night, having a FLIR mode in the TADS which has sufficient resolution to engage tanks at long range, as well as a Pilot's Night Vision System (PNVS) which allows the pilot to operate in total darkness. AN/PVS-5 night vision goggles will also be carried in the event of failure of the PNVS, allowing operation at very low light levels.

5.4.2 FLIR Simulation. The operation of a FLIR is as follows. An IR image is scanned across a linear array of IR detectors which are coupled to an array of LED's. The modulation of the IR image as it scans each IR detector causes the light output of the corresponding LED to be modulated. The image of the LED array is scanned across the faceplate of a TV pickup tube at the same rate as the IR image, resulting in a video picture that can be displayed on a CRT. The modulation of the IR detectors is proportional to the difference in temperature of adjacent elements of the scanned object. Therefore, the final image consists of shades of gray proportional to the temperature gradients within the scanned object. Because of nonuniformity in the response of each element, a characteristic banding of the image will occur. Very little lag should be noticed, but a slight amount of noise is present. The image can be presented as white hot or black hot. Objects will reverse in temperature gradient during the course of a night. Rain can have rapid effects on the IR scene. Targets such as tanks have their own FLIR signatures.

The simulation of FLIR using processed video from a model board has been studied by Cliff Lowe at the Night Vision Laboratory (NVL), Fort Belvoir. Although an equal probability of detecting a target can be obtained, the actual image is quite unlike a FLIR. NVL is conducting a study to see how CGI can best simulate FLIR. The results of this study will be available by the end of this year. It seems likely, however, that CGI can provide adequate simulation. Each surface of the data base would have an emissivity rather than a color and shade associated with it, and an algorithm would have to be devised to calculate the temperature gradient along the direction of scan. The emissivities will change as the instructor changes the time of day and atmospheric conditions. The FLIR operates in the 10-14 μ region and would require a different fog function.

The simulation of the FLIR would apply to both TADS and the PNVS; however, it is likely that the PNVS would be focused closer to the aircraft.

5.4.3 Window Display at Night. It is important for pilots to be able to operate under NOE conditions at as low a light level as possible, using the unaided eye. Most simulators merely lower the contrast and brightness of the display, but this does not reduce the light level to the correct light level. By using neutral density filters in front of the projector, light levels of 10^{-5} foot-candles can be achieved. At these levels, only the rods of the retina are working and the acuity of the eye approaches the resolution of the display. A very realistic simulation can thus be obtained. Bright lights and weapon flashes cannot be displayed and it may be necessary to provide for both types of night simulation.

As an alternative, the bright lights could be displayed on the helmet-mounted displays. The brain readily accepts images seen in only one eye as if they were actually seen in both. The lights would be displayed no matter what imagery was being displayed on the IHADSS or even if the display had been 'switched off'. The FOV would of course be small, but the field of regard would be limited only by the windows of the actual aircraft.

The AN/PVS-5 night vision goggles will work very well with the window display, as described above. Bright lights will not cause the normal blooming but will be visible if included in the window display.

The window display will also be important when FLIR imagery is being displayed on the head-mounted display. The display will be seen by only one eye and will have a relatively narrow field of view of $30^{\circ} \times 40^{\circ}$. A simple experiment was performed, using neutral density filters to ascertain how well one eye would adapt to illumination levels of 10^{-3} foot-candles while the other eye was observing a bright but narrow field of view. The image perceived by the brain was identical to that seen by a normal dark-adapted eye with a bright area in the middle of the field of view. It would appear that in all but the darkest conditions considerable spatial information will be obtained by the eye not using the display.

5.4.4 TADS Display at Night. (The TADS imagery will be derived from a CGI system and displayed on a color CRT as explained in the TADS sections.) In the direct view mode of operation, the image brightness must be directly related to that of the window display. This can be accomplished by using neutral density filters or by direct control of the CRT brightness, depending on the method used for the window display. Bright lights will not appear as bright as they should, particularly when the first method is used. It may be desirable to incorporate a third CRT used solely for bright lights. Its image would be combined with the others but have a higher brightness and not be dimmed at night.

The TV mode will be used primarily in good light conditions but may have a use in moonlight conditions. A reasonable simulation could be provided by reducing the video signal, increasing the simulated lag, and inserting noise. The FLIR mode will be simulated using the techniques discussed in paragraph 5.4.2. The missile mode will probably use a technique similar to that used for the TV mode. Exact specifications for any of the TADS simulated modes of operation will depend upon the final design of the TADS itself.

5.5 TARGETS AND WEAPONS

5.5.1 General. The primary role of the AH-64 is to engage and destroy mobile ground targets, hence this is an essential area of training. The AH-64 simulator must have the capability of displaying such targets and permit tactical engagements. The three principal phases that characterize such a mission are target detection, target recognition, and target engagement.

5.5.1.1 Target Detection. The target detection requirement for the AH-64 pilot or CPG is to detect a moving or stationary camouflaged target at the maximum possible range, i.e., 3000 to 5000 meters. For a tank seen broadside at 2000 meters, a resolution of three arc minutes is required. Smaller targets require greater resolution; however, practical display systems limit the resolution to about six arc minutes at best. Camouflage is an important feature of this task and greatly affects the detection probability. Model systems are capable of good resolution and can provide realistic camouflage for a target. Computer generated systems are also capable of good resolution, but cannot generally provide realistic camouflage.

5.5.1.2 Target Recognition. Target recognition follows as soon as possible after target detection. It is vital for the helicopter pilot to determine the type of vehicle he has discovered in order to know how best to respond to the threat it imposes. Recognition poses two problems in simulation: first, that of creating targets sufficiently detailed to permit ready identification, and second, that of displaying this detail at simulated large distances.

5.5.1.3 Target Engagement. The engagement phase of the mission is no longer concerned with one specific target, but with simulation of the battlefield environment and weapon signatures, such as tracers, missile trails, muzzle flashes, hit designations, small arms fire, and smoke.

5.5.2 Target Simulation Using Model. A terrain model offers an excellent medium for portraying detailed targets in a realistic scenario. State-of-the-art modelling techniques can produce highly detailed targets in scales as small as 800:1, and well designed model boards can present a very realistic background to the pilot. Unfortunately, there are several limitations in the model technique that restrict its usefulness.

Because of limitations in the probe and camera systems (refer to paragraphs 5.7 and 5.8) six arc minutes is the smallest resolvable picture element. According to Johnson's criteria (Ref.5-2), details six inches or smaller are required for identification of a typical tank, and if six arc minutes is the best system resolution, target recognition is only possible for ranges of less than 175 meters. With present techniques, details as small as 0.01 to 0.02 inch can be modelled. If we wish real-world features of six inches to be resolvable, we must therefore use scales of 500:1 or larger. Smaller scales can still provide a recognizable target, but identification will be difficult, and if approached closely, the target will be seen to be of very low resolution. Examples of dimensions in various scale factors are given in Table 5-1. At the other extreme, a scale of 100:1 will give excellent and realistic detail, but the tactical playing area becomes very restricted. A 24- by 76-foot model at 100:1 represents 0.7 x 2.3 km. A further restriction is introduced with moving targets. Not only must the target move smoothly across the model, but it must have sufficient travel to keep moving for a reasonable distance. Large-scale models restrict target movement, while small scales limit the smoothness of the motion because of the small target mass. Needless to say, small scales are also more difficult to work with, especially when handling target vehicles (see Table 5-1).

TABLE 5-1. LINEAR DIMENSIONS IN VARIOUS SCALES

Dimension	Scaled @ 250:1	500:1	750:1	1000:1	1250:1
6"	0.024"	0.012"	0.008"	0.006"	0.005"
1'	0.048"	0.024"	0.016"	0.012"	0.010"
5'	0.240"	0.120"	0.080"	0.060"	0.048"
10'	0.480"	0.240"	0.160"	0.120"	0.096"
20'	0.960"	0.480"	0.320"	0.240"	0.192"
30'	1.440"	0.720"	0.480"	0.360"	0.288"
15 mph.	1.056" /sec	0.528" /sec	0.352" /sec	0.264" /sec	0.211" /sec

We approached the two best modelmakers in the simulation field for their opinions on stationary and moving target scenarios. John Piper of John Piper Simulators Ltd. stressed the importance of target detail for identification purposes. He feels that scales of 100:1 are optimum. He has not yet addressed the problem of moving targets. John Morelli of Independence Model is of a different view. He feels that he can provide good static targets in scales as small as 1000:1, but moving targets would require scales of 500:1 or larger for smooth movement.

Target movement poses a problem in model design. Two methods are presently used. The model vehicle can be connected via a post extending below the model surface to a track or cable drive system. The model, presumably on working wheels, moves along the model surface following a groove which has been precut for the drive linkage. A plastic flap hides the groove until pushed aside by the drive post. Using this system, models can be made to follow contoured surfaces and to negotiate turns. The alternative method is to replace the direct drive with a moving magnet under the model. This requires a smooth surface for the target to move along and limits curves to large radii. Both methods could be adapted to providing continuous circuits, but neither is very flexible. The cut groove method in particular is not easily suited to mosaics of small panels making up a large terrain model. The option of using self-propelled targets is limited to very large scales, in the order of 25:1, and is clearly not suitable for terrain model visual systems.

The remaining requirement is the ability to provide realistic and varying tactical scenarios composed of numbers of fixed and moving vehicles. Groups of fixed targets are very easy to provide with a terrain model board. They can be designed so as to be positionable anywhere on the model, and trees, buildings, and camouflage can also be easily rearranged. The instructor would be required to set up a scenario before each exercise and to enter the target coordinates in the computer data base. Moving targets, if provided, would be less flexible. The route would remain fixed; however, vehicle types could be changed, and varying speeds and directions could be used to prevent the crew from learning a particular target course.

5.5.3 <u>Target Simulation Using Computer Generated Image (CGI)</u>. The mechanics of target simulation are much simpler with a CGI system. Target position is known at all times, since the target is part of the data base. Moving targets are possible, the number of such independently moving targets being limited by the number of available lines and the processing time required. Scenarios can be readily changed by the instructor via his console. Vehicle direction can also be controlled by the instructor, giving unlimited freedom of movement.

The restrictions in a CGI system pertain to the level of detail of the targets and the background. An individual target such as a tank must be constructured out of the available system building blocks, usually edges or surfaces. An estimated 40 edges can create a recognizable tank; however, it appears 'cartoonish' and cannot be identified as any real tank type. Using more edges results in greater detail, but reduces the number of edges to be used for detail elsewhere in the scene. To create a reasonable model of a specific tank type, an estimated 200 to 400 edges may be required. Present CGI systems display no more than 10,000 edges, thus making detailed targets rapidly depletes the background display capability of the system. This in turn limits the ability of the system to provide a sufficiently detailed background clutter to afford camouflage

to the target. Furthermore, any camouflage created only from straight edges lacks the realism of the real world. Thus, though a CGI can produce flexible and dynamic battle scenes, it is not suited to target detection/identification tasks in a real-world environment. It is possible, however, to use 'synthetic' or artificial camouflage to hide a synthetic target. It seems probable that such a system could provide as effective a training in target detection as in a real-world environment. Further studies are necessary to determine the validity of this approach.

5.5.4 Target Simulation Using Superposition or Insertion. The final method of target simulation to be considered was that of superposition or insertion of an externally generated target representation into an existing background scene. Such a target can be generated in one of three ways:

(a) A CGI system can generate the target. Since the system would be dedicated to (single) target generation, all available edges could be used to produce a reasonably realistic picture, although lack of certain geometric figures (such as circles, ellipses, etc.) limit the fidelity of the target. Moreover, the cost of a CGI system is high, and its use solely as a target generator may not be justifiable.

(b) Another method of target generation is to use a large-scale model (50:1 to 100:1) and a second CCTV camera. Combination gimballing of the model and camera, coupled with variable separation and camera zoom capability, would provide a target as seen from any distance or angle. Furthermore, since the camera is only viewing the angle subtended by the target model, a very high resolution is possible. Realism is high using this system, and the costs are moderate.

(c) The third alternative is to use a high-resolution photograph of the target and project it directly onto the scene. This method is cheap, but it gives only a limited viewpoint with respect to the target, i.e., no fly-around capability.

Once the target image has been generated, it must be displayed. With either a CGI source or a camera/model source, a video display is necessary and can take one of several forms. In a dome/projection-type display, such as the USAF's LAMARS, the target is projected onto the dome display by a gimballed projector. In a pancake window or classical infinity display, it can be optically inserted into the scene using a CRT/beamsplitter system. Either system is relatively simple and capable of good resolution, with the dome/projector providing the highest resolution. Another method that has been successfully used on the USAF's SAAC simulator is an inset raster technique. In this system, the background is displayed using a conventional raster, while the target is inset using a high-resolution miniraster which is variable in

size and can be positioned anywhere with the CRT display. Such a system requires a flexible high-resolution display device, in this case a black-and-white CRT. It would not be possible to use existing TV projectors for this since their modulation and deflection circuitry is marginally adequate to produce one raster. Color CRT's are of limited resolution and require complicated driving circuitry to maintain color convergence. However, a field-sequential system using a projection CRT would be suitable for an inset target.

In all of these methods, there are two significant drawbacks. Each system is capable of superimposing only one target. Thus, a battlefield scenario must be produced with a combination of stationary background targets and one superimposed high-resolution mobile target. The second limitation is due to the method itself. In previous applications, the superposition technique has been used to display a target aircraft against a sky background. If the aircraft is bright enough, the sky behind it does not show through. If the aircraft is viewed against a terrain background, the background often shows through, unless some system is used to suppress the background (e.g., keying). Moreover, since the aircraft normally occults the terrain while flying, suppression of the background is correct. However, tanks and similar target vehicles normally travel in such a way as to afford theselves the maximum in camouflage. Thus an inset target must be capable of moving in and out from behind trees and other fetaures in the background scene. To do this correctly requires a detailed knowledge of the background scene content to enable a line-of-sight calculation to be performed. This calculation must take into account all features capable of partially or totally obscuring the target, such as trees, bushes, buildings, other vehicles, etc. At the same time, the display system must be capable of selectively or totally occulting the target projection. With a CGI target generator this is simple. However, with a conventional CCTV system, the only way to do this effectively is to use an inset raster-type target and develop a keying system to selectively insert portions of the miniraster. This is quite difficult to do with any degree of realism because of the limited amount of detail in the line-of-sight data base. Thus one is restricted to just occulting a certain portion of the target, i.e., one half, one quarter. This will result in some disjointed flickering effects as the target passes behind an object. At the same time, because the inset or superimposed target may have a different color, brightness, and/or resolution from the background scene, target detection will become relatively easy. For these reasons, superposition or insertion techniques are not suitable for training target detection. They do, however, offer the potential of higher resolution for target identification and are the most flexible method of introducing a moving target into a model board scenario.

5.5.5 Target Engagement/Weapons Simulation. To correctly simulate battlefield conditions, it is not sufficient to present threat target arrays. The weapons signatures must be simulated, since the role of the attack helicopter is to engage ground targets and to defend itself against threat fire. These effects include tracers, muzzle flashes, mortar and shell impacts,

missile trails, and weapons impact on targets. The three main features to be simulated are as follows:

(a) Visible battleground - mixed random threat and friendly weapons discharges/impacts.

(b) Discharge of guns/rockets/missiles by AAH and impact on target.

(c) Effect of threat weapons, fire, and impacts on helicopter.

A CGI system offers the greatest potential for accomplishing the above tasks. Generation of tracer fire, impact flashes, missile trails, etc., is relatively easy. Weapon fire by the helicopter can be easily displayed and target impacts shown. If required, a destroyed target can then be deleted from the data base or obscured by a cloud of smoke.

A terrain model board system is not as flexible. Simulation of tracers and missile trails must be done by using CGI techniques or an analog special effects system. CAE has had considerable experience with analog special effects for CCTV systems (discussed in paragraph 5.7.10) and feels that such an approach would be adequate. Missile trails and weapon impacts can be indicated by special effects generated flashes, but a detailed model data base is required to determine the point and time of impact. Muzzle flashes corresponding to particular targets on the model are very difficult to generate because detailed knowledge of the exact target location within the displayed visual scene is necessary. An alternative is to insert electronic strobes or flash lamps into the model or the target itself. If the flash is incorporated into the target, the model scale must be large, in the order of 100:1 to cater to the flash dimensions. If the flash is incorporated into the model, the capability to rearrange targets is greatly reduced, although a large array of such flash tubes could be incorporated and randomly addressed. Fibre optics could be employed to reduce the size of the flash points and to remote the strobes behind the model, but target positioning would still be limited.

No matter which system is used, CGI or model board, the weapons signatures can be varied in color and intensity, depending upon the type of signature (muzzle flash, tracer, impact) and perhaps on whether it is a friendly or threat weapon.

5.5.6 Line of Sight Calculation. The one major problem area common to both methods of weapons simulation is the difficulty of (1) determining the actual time and point of impact of a weapon fired from the AH-64 and (2) determining whether the AH-64 itself is within sight and firing range of threat forces. Both these problems are variations on the line-of-sight calculation. The point of impact is generally the intersection of the weapon trajectory with the ground. However, when there are targets moving above the

ground, these must be taken into account and calculated separately. The same holds true for trees and buildings that may intersect the line of fire parallel to the earth's surface. For these cases, special data bases must be provided which detail the surface contour, including trees, buildings, and vehicles, and which indicate the features that are threat targets, both mobile and stationary.

A similar computation must be made in reverse to determine whether the AH-64 is within sight and firing range of threat tanks. This requires a knowledge of the position and type of all threat offensive weapons within a circle of radius three kilometers about the helicopter. If the AH-64 is exposed to threat fire for a sufficient length of time, the helicopter can be deemed 'shot down' or the instructor and crew member alerted. A strobe could be discharged within the display to indicate this condition.

In a model board system using superposition of targets, it is required to determine whether the superimposed vehicle is being occulted by foreground objects.

For this calculation, modifications and additions must be made to either the CGI or the solid model data base. With the solid model, the existing safety system data base is designed to provide only ground contour information. It excludes some surface features, such as trees, bushes, vehicles, etc. These features are essential to the line-of-sight calculation and must therefore be included in the data base. To do this properly requires that the model target area be separately measured and a special data base created detailing the overall contour of the model surface with all surface features in place. Secondly, the position of all targets must be recorded to permit target line-of-sight calculations. In a CGI system, the existing data base will already contain details of all surface features, so that only the locations of targets must be added.

The computation is a complex one, so that priorities must be assigned to the specific line-of-sight tasks to optimize the system response. The missile or weapon impact point calculation should have highest priority. Any significant delay in indicating the impact detonation will be evident to the gunner and seem unreal, particularly if the projectile should fly through an obstruction. However, this calculation is relatively easy. At each iteration the main computer will calculate the missile position on its trajectory, and it is necessary only to compare this position with the contour height and scene content at the same latitude and longitude. If the missile is below the contour, an impact is designated. The maximum lag will be one iteration. Using an iteration rate in the order of 20-40 Hz, this should not be noticeable.

The next priority should be assigned to the laser designator/rangefinder. It must respond quickly and accurately as soon as positioned, since this device must indicate the range to the targets to enable ballistic corrections to be calculated by the tactical computer and serve as a navigational aid. This device requires a full line-of-sight calculation.

The equation of the line of sight must first be generated. Then blocks of scene data that fall along this line in the horizontal plane must be called from the data base and processed to determine if the line of sight intersects a surface. If so, the range to the surface is calculated and the computation is terminated. If not, the next block of data is called in. This proceeds until a surface is found, the laser rangefinder range is exceeded, or the data base limit is reached. Because of the potentially large amount of data to be processed for each calculation, a large amount of computation time may be required. A rough estimate indicates a time of between 200 milliseconds and one second for this calculation, based on an average instruction execution time of two microseconds.

The remaining line-of-sight calculations to determine if the helicopter is visible to an enemy gun have the lowest priority. These calculations can be done in the same manner as for the laser rangefinder, with both endpoints of the line of sight known. Since the range of most threat antiaircraft weapons is about three kilometers, the calculation can be further limited to threat weapons within a three kilometer radius of the AH-64. This calculation is also time consuming, so that the total number of such calculations is limited by the available computer time. A lag of up to five seconds is probably permissible since the helicopter must be exposed for at least this period of time before it is likely to be spotted (Ref.5-8). This would allow for a maximum of about 10 targets, assuming up to 500 milliseconds for each calculation. The same calculation would serve to determine target occultation in a terrain model board/target superposition system.

5.6 TADS SIMULATION

5.6.1 TADS System. A detailed description of the use of the TADS is given in Section 4 which deals with weapons and sighting systems. This section deals with the method by which the actual image seen in the TADS can be simulated. Four different types of images can be displayed on the TADS, each with varying degrees of magnification. The direct view optic has two powers, approximately X3 and X18, and will probably have a circular image format. The daylight TV is monochrome and has a narrow FOV of about $1/2^{\circ}$ to 1° and a medium FOV of about 4°. The FLIR is also monochrome and has a narrow FOV of 2° to 4°, a medium FOV of 8° to 10°, and a wide FOV of $30^{\circ} \times 40^{\circ}$.

Ref.5-8. Barnes, J., Use of Tank Main Gun for Defense Against Helicopter Attack, U.S. Army HEL Technical Memorandum 11-72, Aberdeen Proving Ground, 1972.

The missile TV will probably be IR and have a narrow FOV. Little is known about the missile TV at present; however, if the first three images can be simulated, little difficulty will be experienced with the missile image. The PNVS video can also be displayed, but this will eventually be identical to the wide-angle FLIR image.

In addition to the imagery, various types of symbology can be displayed from the symbol generator. The TV sync standard has not been agreed upon but it seems likely it will be the region of 800 to 900 lines at 60 fields per second. It would seem likely that all TV equipment onboard the AH-64 would have the same standard. It would be logical, therefore, to have all simulated displays use the same standard.

5.6.2 Design Approach. If a model board is used for the main window display, it would be advantageous to be able to use the same viewpoint for the TADS, but with the appropriate magnification. This would enable the copilot/gunner to see a magnified view of the image in the window display. However, in order to achieve sufficient resolution at the high magnification, a probe with an entrance pupil in excess of 20 mm would be required. Such an entrance pupil would require large front-end optics and is, therefore, impractical.

A CGI in the TADS would seem to be the only solution even for a model board system. The data base would have to be as nearly identical to the model board as possible. Restrictions in the number of CGI edges may cause a considerable reduction in the content of the image; however, the copilot/gunner should be able to accept the overall presentation, providing the targets are identifiable and are occulted correctly by the terrain. The significant advantage of a CGI TADS when used with a model board is that it can extend the useful area of the model by the maximum range of the TADS. In this way, an attack area can be placed near the mirror around the model, and targets can be seen in the TADS several kilometers beyond the model boundary.

The different magnifications can be readily achieved in a CGI system by changing the viewing angle. Atmospheric effects can be inserted under instructor control. Weapons effects can be inserted into the data base, and parameters particular to each mode of operation can be simulated. FLIR similation is possible and is discussed in paragraph 5.4.2. Further details regarding CGI simulation of the TADS are given in paragraph 5.13.3.

5.6.3 TADS Display. If the same sync standards are used for the display as are used in the AH-64, the resolution of the simulated TV modes can be identical to the aircraft systems.

The direct view optics, however, should have a resolving power five or six times greater than the TV or FLIR for a given magnification and should also be in full color. The only way to obtain the required resolution over the full FOV would be to use a mosaic of CRT's, which is not very practical and introduces several other problems.

It should be sufficient merely to have a high-resolution target because the main purpose of the high magnification direct optics is to identify the tank. This can readily be done in the system shown in Figure 5-11, using two CGI display images. The computer calculates the tank image, creates a black image on the background CRT, but draws a colored image on the target CRT. This magnified target is optically minified and combined with a beamsplitter into the background image. Occultation and rotation of the target will occur naturally, but movement across the background will have to be provided by a system of mirrors. A magnification of six will give a target resolution of about three seconds of arc, which is probably better than the TADS optics. A magnification of three or four would be more appropriate.

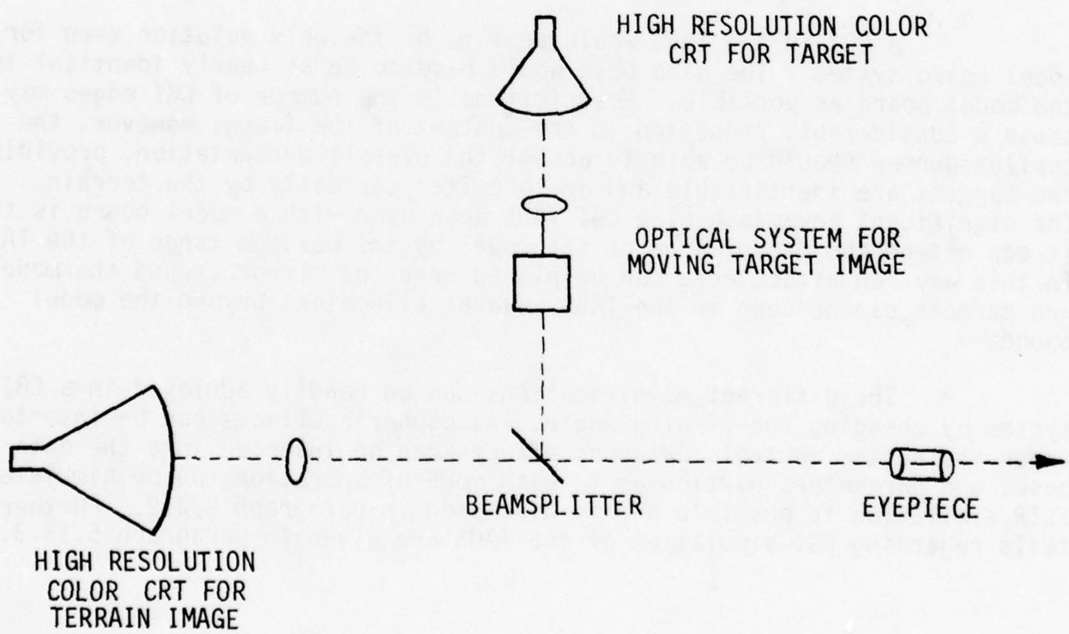


Figure 5-11. TADS Display System Allowing High Resolution Targets to be Inserted into the Background Image.

The monochrome CRT of the actual TADS would be replaced by a high-resolution color CRT and switched to monochrome to display the TV and FLIR. The contrast and brightness controls would not be operable if the copilot/gunner had switched to the Direct View Optics (DVO) mode.

5.6.4 Viewing of TADS. The TADS will normally be viewed through the copilot/gunner boot display which presently contains one eyepiece. The TV modes can also be viewed on the copilot/gunner's panel display, the copilot/gunner's helmet display, or the pilot's helmet display. The video can also be recorded for viewing at a later date.

The acquisition of targets will be performed almost entirely by using the TADS. It is probably most important that the effectiveness of each mode of operation in acquiring targets be simulated accurately. This should ensure that the copilot/gunner uses the TADS in the same way in both simulator and AH-64.

5.7 CAMERA

5.7.1 Choice of Camera Type. Considerable time and effort have been spent by numerous simulator manufacturers in trying to develop a high-resolution color TV camera. A standard line rate simultaneous Philips camera was used for many years with great success by Redifon. Selection of tubes and boosting of the video at the higher frequencies enabled a reasonable quality picture to be presented to the pilot. Singer developed a four-tube simultaneous camera using a high bandwidth luminance channel and a low bandwidth chrominance channel. The basic reason for this approach is to reduce registration problems that are inherent in simultaneous TV. The logic for reducing the chrominance bandwidth is based on the lower acuity of the eye in the red and blue portions of the spectrum. The argument fails to take into account, however, the close viewing distance in simulator applications, which causes the visual to be device-limited rather than eye-limited. The four-tube approach was tried by the commercial TV networks during the 1950's and abandoned shortly thereafter. The technique chosen by CAE and Grumman is the field-sequential color camera which was originally developed by CBS a number of years ago and nearly became the standard color system in the U.S. The three basic reasons for commercial rejection of this system were:

(a) Higher bandwidths required

(b) Noncompatability with existing black-and-white TV

(c) The rotating drums required on each home TV set

None of these restrictions is valid in CCTV and in particular simulator applications.

The first color TV was based on a field-sequential system. Early workers such as Baird realized this was the most logical method for obtaining color. It was in fact the broadcasting authorities who encouraged the development of a system which would be compatible with black-and-white TV. This is an unnecessary limitation for a high-resolution camera to be used in CCTV applications. The basic concept of simultaneous TV is optical separation of the red, blue, and green components of an image, electronic processing of each colored image and the merging of the three images optically to give a full color picture. Such a concept does not naturally lend itself to obtaining an image as faithful as possible to the original object.

The field-sequential concept uses the same optical and electronic channel for each color except for the color wheel filters themselves, which are of unity power. No registration problems exist and equal resolution can be obtained for each color.

CBS designed a TV camera using the field-sequential technique for CAE in 1971 and this has since been refined to its present high standard. The sync standard used on the CH-47C for Iran is 735 lines at 150 fields per second. We could increase this to 925 lines at 180 fields per second to give a little more vertical resolution and make it compatible with the 60-Hz line rate. The modulation transfer function (MTF) shown in Figure 5-12 would remain unaltered, giving an 800-line limiting resolution in the horizontal direction with high MTF at the intermediate spatial frequencies.

Apart from trying to achieve a high MTF under static conditions, it is most important to achieve a reasonable MTF under dynamic conditions. The field-sequential camera is well suited to do this, since to achieve reasonable color the tube must be low lag, and the effect of the lag is reduced further by scanning the image at three times the normal rate. The high angular turn rates experienced in helicopters make dynamic resolution a very important parameter.

From the preceeding arguments it appears that the field-sequential concept offers the best approach for high-resolution TV systems. The remainder of this section deals with the problems of field-sequential TV systems.

5.7.2 Image Tubes. Many image tubes were considered by CBS before deciding to use the RCA image isocon. This was originally tried with an image intensifier to reduce the model illumination but gave a very noisy picture. Next, a number of 4827 isocons with various target-to-mesh spacings were tried by CAE and finally one was chosen with a 0.002-inch spacing as being the most suitable. This has been used ever since, and although RCA no longer makes the 4827, it can make an identical tube, giving it a prototype C-number.

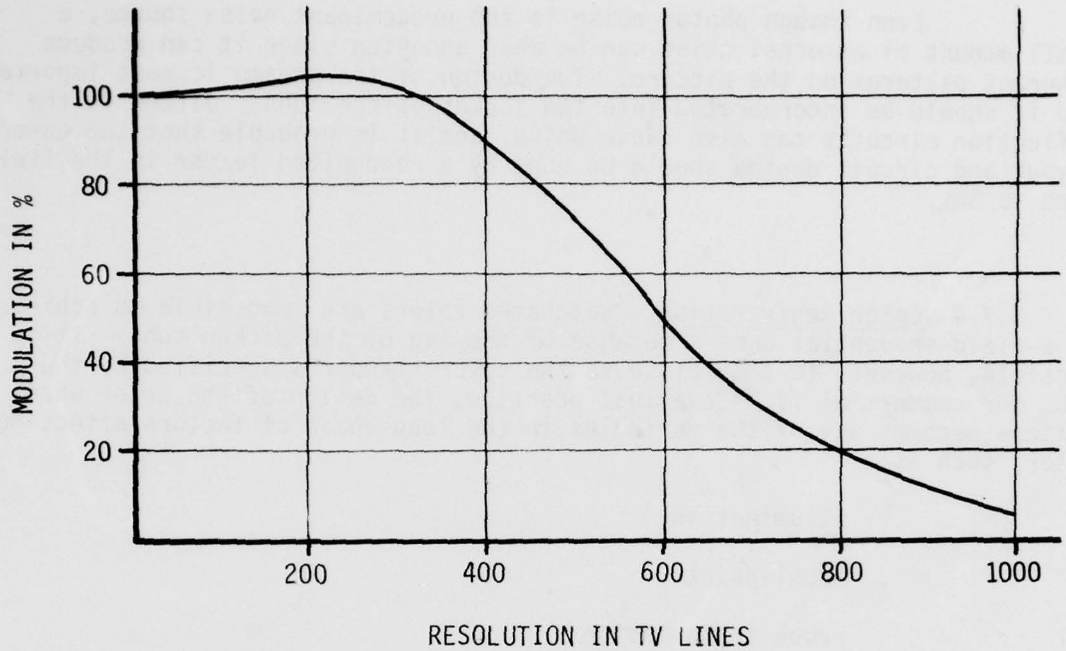


Figure 5-12. Modulation Transfer Function of CAE Camera.

The chalnicon tube has received much publicity lately, and SRL made a camera using this tube for Farrand. It would seem to have excellent resolution and noise characteristics but appears to be too laggy for field-sequential use. An English Electric isocon Type P8040 is now being tried, but it would appear to be inferior to the RCA 4827. RCA now manufacture a physically shorter version of the 4827 which, if it provides identical performance would be a good candidate for a visual system requiring multiple cameras.

5.7.3 Camera Noise. As stated in the previous paragraph, the image-intensifier isocon was rejected for noise reasons. An analysis of the noise processes in an isocon show that photon noise is by far the most important parameter. This implies that for a photo cathode of a given quantum efficiency the noise is entirely dependent on the input light level. Experience has shown that light levels in the region of 0.03 foot-candle on the faceplate give reasonable signal-to-noise ratios.

Even though photon noise is the predominant noise source, a small amount of external noise can be most annoying since it can produce coherent patterns on the picture. The design of the preamp is most important and it should be incorporated into the socket of the tube. Jitter in the deflection circuits can also cause noise, and it is probable that the camera layout and circuit design should be done by a recognized leader in the field, such as SRL.

5.7.4 Color Registration. Saturated colors are impossible to achieve in a field-sequential camera because of the lag of the pickup tube. It is possible, however, to come close to the color standards specified by the NTSC for commercial TV. In actual practice, the design of the color wheel filters becomes one of the variables in the long chain of factors affecting color, such as:

- Illumination
- Model paints
- Probe transmission
- Camera
- Display

A computer program has been written to optimize the displayed color, given the parameters of each item.

5.7.5 Maintenance. The field-sequential camera is very easy to maintain and can go several days without being touched. The MTF of a high-performance video chain degrades gracefully and usually maintains the same limiting resolution. It is usually impossible to determine which element in the chain is causing the degradation. Therefore, it is important to be able to isolate the three major elements. The display can be checked by using electronically generated resolution patterns, and the camera can be checked by using a high-quality lens of a known MTF in place of the probe. This automatically checks the probe.

5.7.6 Electronic AOI Control. Because of the possibility of using an AOI approach for increasing the effective FOV and doubt concerning the performance of a mechanical system, it was decided to investigate an electronic technique for moving the displayed image. The movement could only take place in the horizontal direction, which in this system would be

perpendicular to the scanning line. In normal TV parlance, this would be in the vertical direction. It was realized that a simple technique of delaying the vertical sync of the camera relative to that of the display would cause the image to move in the required direction. A specific relation would have to exist between the vertical sync of each display to allow the camera video to be switched at the appropriate time and appear to travel smoothly from one display to the next. Similarly, a specific relationship would have to exist between the vertical sync of each camera. For the color to remain synchronized, each color wheel must remain synchronized in phase to the vertical sync of its own camera rather than to the power frequency.

The system would work, but careful attention would have to be paid to the design to minimize discontinuities in the image. Since completing this part of the study, a parallel mechanical engineering study has shown that a system of hydraulic actuators is quite capable of moving three projectors at the required rates. A mechanical approach would appear to be preferable since it allows movement in both yaw and pitch and requires only three projectors. If the five pancake window display is used, the electronic approach would be used.

5.7.7 <u>Camera Lag and AOI.</u> Model board visuals using TV cameras suffer from a loss in resolution due to lag. A scanned image also suffers a loss in modulation at various frequencies because of the interaction of the scanning rate with the image motion. Both effects can be eliminated by slaving the probe and projector to the observers eye. Since we only intend slaving the probe movement to the observer's head, a slight loss in resolution will still be apparent. In a system using a 180^o probe to obtain a large fixed FOV, the loss of resolution in the side windows at high forward speed could be severe.

It is interesting to note that the interference between scanning rates amd image motion mentioned in the previous paragraph occurs at much higher angular rates when using a field-sequential system. Arthur Kaiser dealt with this point and many others in his paper on field-sequential television presented to the SPIE annual conference in 1975 (Ref.5-9).

5.7.8 <u>Color Breakup.</u> The potential problem of color breakup was anticipated when CAE designed its first visual system. It was calculated that the effect would be small during the normal maneuvers of a commercial airliner. However, when the system was assembled, it became apparent that no

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Ref.5-9. Kaiser, A., <u>Field-Sequential Color TV for Visual Simulation</u>, Proceedings of the SPIE, Vol. 59, Anaheim, March 1975.

color breakup could be seen at all. The reason for this was only discovered during the design of the rotor blade special effect for the CH-47C.

Being aware of the possible problem of color breakup, the circuit was so designed that the motions of the rotor blade were suspended for each color sequence of red, green, and blue. This should have resulted in a white rotor blade, but as soon as it started to move, a distinct color fringe was observed on each side of the rotor blade. It was then noticed that when the circuit suspending the motion for the three color fields was inhibited, so that the red, green, and blue images were now separated, the fringes disappeared. The explanation then became obvious. When the eye looks at a moving object it tracks the object to keep the image on the center of the fovea. Therefore, although the red, green, and blue images were separated on the screen, they were together on the retina, resulting in a white image. The background will, conversely, have color breakup, but as the acuity of the eye drops off sharply away from the fovea, it is not seen.

CAE has demonstrated the CH-47C visual to many people, and no color breakup has been apparent under normal operating conditions.

5.7.9 Color Fringing. An annoying problem in the field-sequential system is color fringing caused by electro-magnetic fields synchronized to the power frequency. This is analagous to the registration problem of simultaneous TV. However, once the source of the interference has been found and eliminated no further action is required.

5.7.10 Special Effects.

5.7.10.1 General. In a CCTV system, it is necessary to generate certain display features electronically rather than incorporating them into the model. This appears to fall into two categories:

(a) Diffuse shapes, with gradual or indefinite boundaries, such as fog areas, dust trails, smoke, etc.

(b) Discrete lines or dot patterns, such as tracers, missiles, rockets, enemy flashes, etc. Some of these are rapidly moving dots (or flashes), others are semi-stationary lines, and still others are stationary dots.

In all cases, a capability for displaying a distinctive color is required.

In the field-sequential TV system, this usually requires a signal to be generated at the same position in each of three successive fields, but with a different amplitude in each field. In the case of rapidly moving patterns, a compromise is sometimes required. If one position is maintained for three fields, the apparent motion may appear to occur in large jumps; on the other hand, if the pattern is allowed to move between fields of different colors, a condition of "color breakup" may arise. This problem may exist for the simulation of rockets and missiles and is expected to require experimental evaluation in order to determine the preferred approach.

The basic display mode is a raster system, i.e., the spot occurs (and retraces) across one dimension rapidly while simultaneously moving relatively slowly along the other dimension. In the proposed system, the rapid scan (probably in the range of 60 to 70 kHz) will be the vertical axis, and the slower scan (at three times the power line frequency, i.e., 180 or 150 Hz) will be horizontal. The deflection system is fundamentally in an analog format with continuously variable linear analog deflection waveforms.

As will be discussed later, analog techniques, based on the above linear sweep deflection voltages, appear best suited for generating diffuse patterns such as fog, dust, etc. The discrete patterns of sharp lines or dots may be more readily realised by digital methods, although analog techniques may be adaptable. The use of digital techniques would require a digitization of the master display spot position. For the slower (H) axis, this is readily done by correcting V-sweeps. On the fast axis (V), however, operating with a resolution of several hundred picture elements at a sweep rate approaching 70 kHz, the circuitry would have to operate at 50 MHz or higher. This is a severe but not impossible requirement. This matter would require further study before a recommendation could be made as to which method is preferable. The requirement could be eased if it would be acceptable to accept a lower resolution for the special effects than would apply to the terrain model video.

5.7.10.2 Diffuse Patterns. A method for generating a continuously variable fog pattern has been developed by CAE and successfully incorporated into CCTV visual systems already produced. To the observer, the effect is based on an analog control voltage designated RVR. As the RVR is decreased from maximum, a narrow band of fog appears at the horizon and increases in width. Fog extends more rapidly above the horizon than below; at an intermediate RVR value, the complete area above the horizon is covered with fog, but only part of the terrain is masked. At zero RVR, the entire scene is blank white. Considerable care has been taken to provide a realistic onset of fog, in that there is a relatively wide transition zone; if this is not incorporated, an unrealistic 'window-blind' effect is produced.

The analog circuitry to generate the above effect follows roll and pitch maneuvers of the aircraft, so that the fog pattern appears to remain fixed with respect to the model. This is achieved by mixing linear H and V ramps, whose amplitudes are proportional to 'cos roll' and 'sin roll', respectively, and with an appropriate 'sin pitch' term also added. This composite voltage is compared with the RVR voltage, and the resultant (continuously variable) difference voltage is used to control a video change-over circuit which accepts camera video and fog video to provide a controlled composite video, in which the proportion of camera-to-fog signals is continuously variable.

5.7.10.2.1 Fog. The basic CAE system described above appears to be readily adaptable to the AH-64 requirement. To accumulate a fog bank covering several displays horizontally, particularly under roll conditions, separate pitch and roll analogs are necessary for each display. Roll for the forward display should be equal to aircraft roll, but for the side displays, pseudo-roll and pitch angles should be computed to correspond to horizon position on that display. Each display should use a straight line approximation to the actual horizon position and orientation, calculated for proper registration where the displays merge.

An additional feature, already available in the CAE design, may be useful, e.g., flight over cloud. This is produced with negative RVR values and results in the display of blue sky above the horizon, merging to white cloud (or fog) at and below the horizon, which correctly follows aircraft attitude changes.

5.7.10.2.2 AH-64 Generated Smoke. This pattern would produce a blank oval area on a portion of the display, masking a particular target and surrounding FOV. The normal view of the model would, however, be seen outside this restricted area.

The analog sweep waveforms used to generate the fog control signals can be extended to define elliptical or circular areas on the display by using them to generate H- and V- parabolas, which are then combined. The full details of such a system, including shape, size, accomodation for roll and pitch, etc., will have to be developed. Use of a noise generator to create a flickering edge to the edges of the pattern may be desirable. In any case, the edges of this pattern would diffuse to produce a gradual transition from full smoke to clear terrain. The position of the smoke pattern would, of course, be under computer control, and the color would be adjustable, if required, to other than white, e.g., brown, gray, etc.

5.7.10.2.3 Dust Trail. An analog method similar to that described above can be used to produce a smaller elliptical area simulating the dust cloud from a column of vehicles. In this case, the edges, particularly the lower one, might have to be more abrupt than the smoke area. It is also possible that the complete pattern should consist of only the upper half of an ellipse with a relatively flat lower edge. These problems would require further investigation, but the basic approach appears to be feasible.

5.7.10.2.4 Rotor Blade. This simulation has been developed by CAE and incorporated into an existing simulator visual system, primarily using analog techniques.

There is an inherent problem in presenting the pattern of a rapidly moving helicopter blade at frequencies corresponding to rotor speeds in the 290-rpm range on a TV display having a relatively low color frame rate equal to the power line frequency (50 or 60 Hz). This is due to the fact that in one color frame period, the blade should ideally move almost half of the display width. Unless special measures are taken, spurious beats, color breakup, and undesirable stroboscopic effects are seen.

Special demonstrations in an actual helicopter were arranged for a CAE circuit designer to observe blade patterns in the real world. As a result, it was possible to arrive at an acceptable compromise for practical simulation as follows:

(a) At low speeds, up to approximately 45 rpm, a discrete moving blade pattern is seen. The shape is trapezoidal. The speed of motion through the FOV is sufficiently low so that the observer is conscious of the shape and direction of motion, and the blade motion steps are relatively small. A sample and hold circuit maintains the blade position fixed for the three color fields of one color frame, avoiding color breakup at the edges. The blade color can be set to any color and intensity desired; in most cases, a black blade is simulated. This range of simulated rotor speeds would normally apply only on the ground.

(b) At speeds in the flying range (180 rpm and higher), it was found that the observer no longer sees a discrete blade pattern, nor can he sense the direction of rotation. A realistic simulation is thus possible merely by flickering the upper portion of the display, above the blade tip, at a frequency approximating the rotor speed, which for a three-blade rotor is 19 to 20 Hz for 280 to 300 rpm. This is done by attenuating the video above the blade tip path during one complete frame for all three rotors.

There is a range of speeds above 60 rpm when the sudden changeover from discrete to flickering pattern is a compromise in realism. However, since this speed range occurs relatively infrequently and not in-flight, it is considered to be a reasonable compromise.

The height of the blade tip on the display is under computer control to simulate variation with speed, lift, etc. In the existing design the tip moves in a symmetrical curved path (parabolic) to simulate the inclination of the blade tip plane with respect to the 'horizontal' reference axis of the helicopter. Some refinement of this feature would be required to cope with the larger number of displays covering a wider FOV and possibly to introduce asymmetry to the tip path.

If a display position digitizer becomes necessary for generating some of the discrete blade patterns to be described later, it might be possible to convert portions of the rotor blade simulator to digital circuitry. However, the existing CAE analog design performs quite satisfactorily, and there would appear to be little advantage in embarking on a new development program for only a potentially small benefit in circuit hardware reduction.

Additional circuitry will be required to synchronize the motion of the blade across the three, four, or five displays, so that it correctly simulates crossing the boundaries between displays.

5.7.10.3 <u>Discrete Patterns</u>. All of the remaining special effect patterns involve discrete points or narrow lines, rather than diffuse-edged patterns, and digital techniques can be considered for their generation. As discussed earlier, digitizing positions on the fast (V-) display axis involves high-frequency logic circuitry if full resolution capability is to be retained.

Regardless of whether analog or digital circuitry is to be used, most of these functions are generated by comparing the instantaneous H- and V- spot positions of the display raster with positions defined by the computer and by outputting an appropriate video pulse when they coincide. To draw a line, as distinct from a spot, on a raster display, additional interpolation circuits may be required.

5.7.10.3.1 <u>Missiles</u>. It is proposed that up to four missiles be simulated with moving dots on the display. The apparent motion between color frames (50 or 60 Hz) can be handled by the computer in real time. Four pairs of X-Y output values, one for each missile, will be required of the computer in either analog or digital format.

A dot will be generated at each X/Y (H/V) coincidence. Experiments will be necessary to determine whether the dot should have a finite size (i.e., bracket a few slow scan lines and be slightly elongated in the fast axis), or whether the smallest possible spot is preferred.

An intensity value must also be provided by the computer. The circuitry will allow the brightness of the spot to decrease as it recedes. It is proposed that one common color adjustment be provided for all four missiles.

It appears possible to simulate the impact of a missile by generating a larger and possibly diffuse spot which could appear momentarily at a computed position and disappear in a relatively short interval. A further study of the characteristics of the real-world effect would be desirable. An effect similar to (but considerably smaller than) the vehicle dust trail discussed earlier (paragraph 5.7.10.2.2) could possibly be used.

5.7.10.3.2 Rockets. Salvos of up to eight rockets may be simulated in a manner similar to that of the missiles, with one additional feature. Rather than programming all eight rockets individually to provide for spread of their tracks, one reference track will be computed, and the special effects unit will introduce an appropriate divergence into the remaining tracks. An impact explosion or air burst could be simulated by a momentary bright flash of programmed color, intensity and duration, for each rocket of the salvo.

5.7.10.3.3 Enemy Flashes. Simulation of enemy flashes is achieved by generating momentary bright dots, or small areas, at programmed locations. A further study is required of the duration and frequency of such flashes as well as color variations in order to establish if more than one such flash can be displayed simultaneously. It is possible that one common signal generator would be supplied to simulate missile and rocket impacts and enemy flashes.

5.7.10.3.4 Tracers. For simulation of tracer bullets, the display could consist of a single straight line (or vector) which decreases in intensity toward the far end until it becomes invisible. Since all such vectors will have large components along the fast scan (V-) axis, all amplitude level changes will have to be introduced during each color field.

A more detailed study is required to arrive at the preferred general approach to this simulation, involving the generation of vectors on a raster display and the way to cope with ricochets and bursts.

It may be possible to simulate tracer trails of different colors to simulate enemy fire. The feasibility of multiple tracers, color differences, as well as the optimum format for computer data to define trail position and orientation, will all have to be studied.

5.7.10.4 Sky. The region above the model contains lights, building construction, etc., which may be viewed by the camera at high pitch angles, particularly if looking along the full length of the model from near one end. Although a wall, approximately 30 inches high, will be provided along the edges of the model in many situations it will be possible to see above this boundary. Some form of electronic sky generation is desirable.

CAE has experience in this field. In a DC-10 simulator for Air New Zealand, using a relatively flat model, an electronic sky was provided consisting of a blue upper region, merging to a whitish haze at the horizon. This electronic sky performed well. The artificial horizon correctly followed aircraft attitude changes. The system had one limitation, i.e., the sky cut off any objects extending above the horizon.

In the Iranian CH-47C simulator, using a model of mountainous terrain, it was not acceptable to have the sky override the mountains above the true (ground level plane) horizon. An electronic keying scheme has been employed in an effort to overcome this problem and has had reasonable success. A wall is provided around the edges of the model, extending a few feet higher, and is painted black. A video detector senses if the video level is below a certain threshold (as expected when scanning the black backdrop), or above it (as when scanning the model area). If below threshold, the electronic sky is switched in. Some problems remain with this system in dark or shadowed areas of the model, which tend to be interpolated as 'black', and where spurious blotches of sky appear. A storage system is being evaluated that will not permit the sky to be enabled once the display raster scan has detected continuous video during a horizontal scan; this scheme is not yet perfected but shows considerable promise.

For the AH-64 Simulator, the V and H scan rates will be interchanged, i.e., the vertical scan is the high-frequency and the horizontal the slow axis. This should make it possible to provide keying storage on each V scan time. For example, in scanning from top to bottom, the sky would at first be inserted until the spot first reached a visible object in the model, whereupon the sky would be inhibited and camera video enabled for the remainder of that V scan. This system should work well for bulky objects, buildings, mountains, etc., but it would have limitations if, for example, sky were to be seen behind a fine structured item such as a tree.

Further development work is required in this area, but it is felt that a satisfactory system for inserting an electronically generated sky can be provided through a coordinated approach involving the following:

- Model lighting
- Backdrops
- Certain details of the model itself
- Electronic circuitry

An alternate approach that would not involve as much keying should also be investigated. With the backdrop painted blue or white (to simulate sky), it may be possible to merge an electronic sky of similar color, based on computed data on the location of the top of the backdrop in the scene. A transition area in the sky portion of the composite picture might still be visible, but this may well be an acceptable compromise. It would also be necessary to arrange that high features of the model did not extend above the painted backdrop.

5.7.10.5 Video Combining and Switching. In order to preserve the bandwidth and not degrade the signal-to-noise ratio for the main camera video signal, it is important to arrive at a video circuit design that minimizes the number of video switching or combining circuits through which the camera signal must pass.

An investigation will be required to find the best way to insert, particularly, discrete synthetic signals such as flashes, missiles, etc. Some circuit simplification is possible if these signals can simply be superimposed onto camera video without the need for actual video switching. However, there is some doubt that correct color retention can be maintained against various background colors if this simpler approach were followed.

5.8 PROBE

5.8.1 General Discussion. The optical probe can be considered one of the most important single elements of the CCTV/terrain model board visual system, since to a large extent it controls or determines many of the physical and performance parameters of the remainder of the system. Specifically, the probe performance affects the following:

- Model scale, limited by probe clearance.
- Model illumination, controlled by probe T/No. and F/No.
- Display mapping function, determined by probe mapping
- System resolution, contribution due to MTF of the probe
- Visual system response, in its rotational degrees of freedom, determined by smoothness and response of the rotational drives contained within the probe.

The optical probe serves as the pilot's eye for the visual system. As such, the center of the probe entrance pupil must be located at the correct pilot eye height above the model. For an eye point nine feet above the ground in a 750:1 scale model, the actual probe height must be 0.144 inch. Since this is the position of the center of the entrance pupil, the actual lens structure must extend below 0.144 inch. Present side FOV probes extend 0.130 inch below the entrance pupil, giving a clearance of 0.014 inch on a 750:1 model.

The optical probe is a complex assembly of lenses, prisms, and mirrors. As such, it must be expected to have limited light transmission and restricted image contrast. High-quality antireflection coatings are used to give reasonable scene contrast and transmission. Spectral transmission and chromatic aberration (both lateral and longitudinal) must be carefully corrected to present a high-quality color image to the television camera.

Wide-angle probes can be designed with any of several mapping functions. Each specific mapping function (Fθ, Ftan θ, Fsin θ, etc.) has its own advantages and disadvantages. The choice of a mapping function depends upon the FOV to be covered and the type of display system being used.

The pitch, roll, and heading movements of the aircraft are generated in the probe. Heading and roll must be continuous, but pitch can be restricted for helicopter simulation. All axes must be capable of responding quickly and smoothly to changing aircraft attitudes. For most helicopter work, rates of the order of one radian per second should prove acceptable. For the AH-64 the following requirements of probe performance are considered as the minimum acceptable:

- Pitch $+30^{0}$, -50^{0}
- Heading 360^{0} continuous
- Roll $\pm90^{0}$
- Rate of Turn (in any axis) 1 radian per second

The biggest problem in designing a probe/CCTV system is that of providing sufficient depth of field with good focus. In a normal optical system, the plane of focus is perpendicular to the axis of the system. The depth of field is an asymmetrical region about the focal plane which varies as a function of the point of focus and the lens aperture. The region of good focus increases with diminishing aperture and decreases with closer focusing. The limit of aperture size is determined by the Rayleigh criterion for diffraction limit, and is about 1 mm diameter for three arc minutes resolution. The problem then arises that in the near-to-ground or on-ground condition the depth of field cannot cover the full FOV. A partial solution is obtainable by using the Scheimpflug or tilted lens technique as perfected

by Farrand. By tilting lenses in the optical path, it is possible to tilt the focal plane of the object. This technique can be used to place the ground plane entirely in focus; however, the depth of field now lies parallel to the line of sight, and vertical objects on the model may go out of focus.

At present, the Farrand Optical Company produces several probe models covering up to 140° diagonally. Considering the wide FOV requirement of the FWS display, a 140° Farrand probe is recommended. However, the decision of whether to use a tilted or non-tilted probe requires further consideration.

5.8.2 Tilt vs Nontilt. The original probes used in aircraft visual simulators were of the nontilt variety. Typically, the aircraft simulated were commercial airliners or military fixed-wing aircraft that flew over scale models of the order of 2000:1 scale factor. Under these conditions, on-ground focus was poor at best, particularly since apertures had to be large to accomodate the low sensitivity of existing television cameras. Under these circumstances, the Farrand tilt-corrected probe offered a major improvement in system performance. On-ground focus was good, optical efficiency was adequate, and limiting resolution remained satisfactory. Since the on-ground maneuvers performed with these systems were restricted to taxi and takeoff runs on flat runways remote from buildings and vehicles, the lack of vertical depth of field was not important. However, the requirements of the new generation of rotary wing aircraft simulators are quite different. An important training maneuver for military helicopters is takeoff and landing from confined areas. In this situation, good vertical focus is essential and is much more easily achieved by using a nontilt probe than by using Scheimpflug techniques.

A comparison of depth of field between the two probe types is shown in Figure 5-13. Using modern low-light level camera tubes such as the image isocon, with high efficiency antireflection coated elements in the probe optics, sufficient light is available to design probes that operate near the diffraction limit. These probes can be either tilt or non-tilt. As can be seen in Figure 5-13, a nontilt probe at 6 mm above the model will have acceptable focus from about 2.5 cm to infinity when focussed at infinity. For a 500:1 scale model, this corresponds to acceptable focus from 41 feet to infinity viewed from a 10 foot eye height. This is adequate for an AAH helicopter, where the rotor diameter restricts the closest approach to vertical objects to about 30 feet. However, by moving the focus point closer, the depth of field will move inwards and good focus can be obtained for closer objects and features in the lower part of the FOV at the expense of poorer focus at infinity. The loss of distant focus is of little consequence, however, since when performing confined maneuvers, the pilot will be concentrating on nearby features. In fact, the plot in Figure 5-13 is for a 1 mm entrance pupil, but this can be reduced to 0.7 mm without significant loss in resolution, further enlarging the depth of field.

Using a tilt-corrected probe under the same conditions as previously described, the surface of the ground would be perfectly in focus over the entire field. However, at the same 41 foot distance, a vertical object would go out of focus at one foot above the ground, clearly an unacceptable situation. By varying the tilt, the plane of focus could be moved to encompass a vertical object, but this would require a knowledge of the position and height of the object and would not prove acceptable for all objects within the FOV. Furthermore, the focus assembly must be varied as the tilt is changed in a compensatory manner. To slew both systems smoothly and in synchronism may prove difficult, especially under rapidly changing tilt conditions as might be encountered in an NOE flight.

Present probe designs offer approximately the same limiting resolution for both non-tilt probes and tilt-corrected probes with the tilt disabled. It has been our experience with the CH-47C visual system that a non-tilt probe is more than adequate for scales of the order of 500:1. However it might prove useful to incur the added cost of a tilt-corrected probe for a prototype system to evaluate the performance of Scheimpflug optics in the AWS simulator. If the tilt feature proved to be of no value, it could be disabled and the probe used in the non-tilt mode.

5.8.3 Special Probes. In considering probes for the AH-64 visual requirements, we investigated several special or modified probe designs. The visual will require a wide FOV. For this purpose two designs present themselves. The first is to use the standard 140° FOV probe with multiple outputs. For the proposed 110° x 50° AOI FOV, three cameras of 50° x 36° could be used. The center camera would use the normal high-resolution center region of the field, with the remaining two cameras on the sides. The side fields would have lower resolution than the center, but for an AOI system the deficiency should present little problem. A simplified version of this probe was used by CAE on the CH-47C terrain model/CCTV visual employing two cameras, one for the forward field and one for the 'chin bubble' field. The success of this system has proven the feasibility of the technique.

Farrand has recently produced a design for a 360° FOV probe, using eight channels of video. This probe has a more restricted model clearance, and the roll and pitch limits are too restricted to permit its use in a helicopter simulator.

When first considering the problem of simulating the TADS system on the AH-64, a dual-view 'piggyback' probe was considered. Two separate entrance pupils, one of restricted aiming capabilities, could be mounted together in the same package. The restricted probe could be used as the TADS pickup for objects within its FOV. However, the TADS direct view display requires a magnification capability of 18X. To maintain a three-arc-minute resolution under 18X magnification, and entrance pupil of about one-inch diameter is required. This is clearly not acceptable, so the design was dropped.

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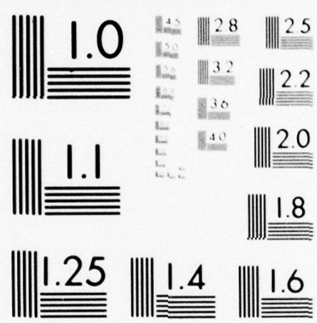


MICROCOPY RESOLUTION TEST CHART

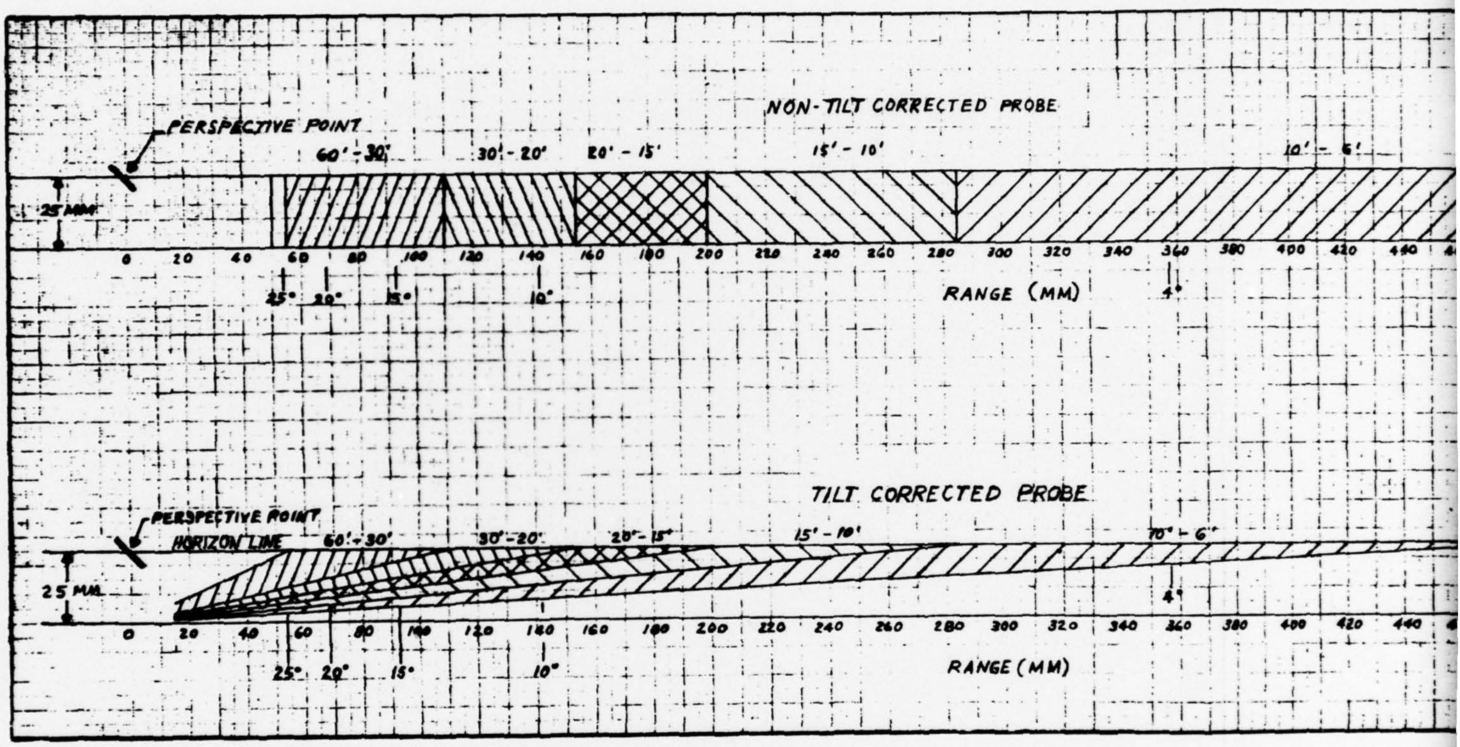
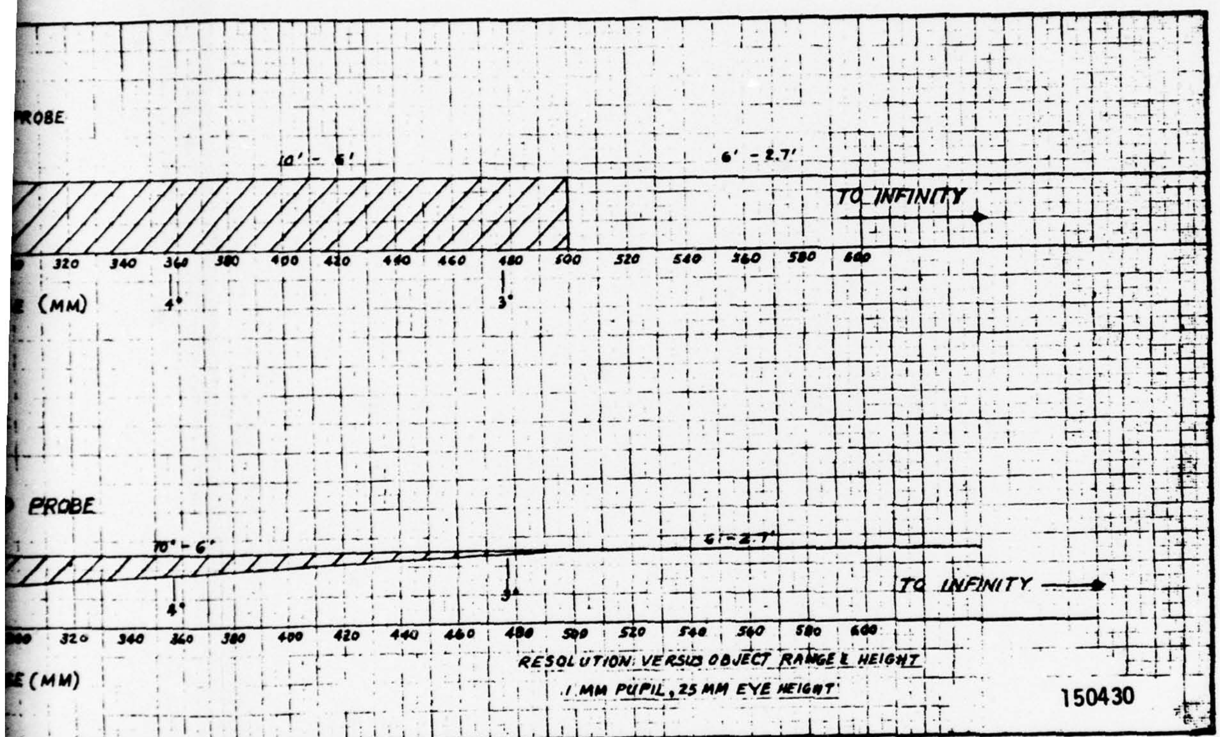


Figure 5-13. Resolution Versus Object Range and Height



FARRAND OPTICAL CO., INC.
117 Wall Street,
Valhalla, New York, 10595

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Farrand has also produced stereoscopic versions of its wide FOV probe for NASA. These probes provide outputs with the normal human eye separation. A stereo model board system is not considered practical for a variety of reasons, so that this probe is only of academic interest.

5.9 MODEL

5.9.1 General. Terrain model board systems have been used for visual flight simulation for many years. As a result, a great deal of study and development effort have gone into optimizing the performance of these systems. Better cameras, better probes, and, more recently, better models have continually improved the visual scene presentation of these devices.

Recent years have produced substantial advances in model board production techniques. Individual models are tailored for the specific aircraft types and mission requirements with the following factors taken into account:

- Playing area
- Scale size
- Terrain detail requirements
- Color quality
- Construction materials

A model board system for the AH-64 FWS must meet exacting requirements. A large playing area is necessary for Nap-of-the Earth (NOE) flight and tactical training. Good detail is essential for target identification and NOE maneuvers. Since the helicopter will fly close to the ground, special safety features must be incorporated to protect the probe from crashing into the model. Finally, good colors must be chosen to provide realistic scene contrast, and dimensionally stable model materials must be employed to ensure consistent probe clearances.

5.9.2 Model Scaling. The four constraints on model scaling are:

- Playing area
- Required detail
- Probe clearnace and focusing
- Safety system

5.9.2.1 Playing Area. From discussions with Army personnel at Fort Rucker and Fort Knox, it was learned that the minimum forward playing area required is about 7 by 15 km, but a larger playing area would be preferred. From Table 5-2 it can be seen that the maximum scale that meets these requirements in a large model board is 1000:1. Smaller scales would give a larger playing area. Model boards larger than 24 by 76 feet could be built and used with larger scales, but such models impose excessive requirements on servo drive systems and building dimensions and are not recommended.

TABLE 5-2. PLAYING AREA VS. SCALE FOR TYPICAL MODELS

Model Size	250:1	500:1	750:1	1000:1	1250:1
21x60 Ft.	1.6x4.6 km.	3.2x9.2 km.	4.8x13.7 km.	6.4x18.3 km.	8.0x22.9 km.
24x76 Ft.	1.8x5.8 km.	3.7x11.6 km.	5.5x17.4 km.	7.3x23.2 km.	9.1x29 km.

5.9.2.2 Model Detail. The level of detail in the model strongly affects the perceived image quality. For most purposes, a moderate level of detail is required, one sufficient to show branches on trees, doors and windows, on vehicles, tire tracks on roads, etc. The smallest model scale that can still provide adequate detail is about 1000:1, where 1 ft. in the model is 0.012 in. in the real world. Larger scales would give better detail.

5.9.2.3 Probe Clearance and Focussing. The optical probe is the image pickup device and as such its physical size determines the closest approach to the model. For a typical Farrand probe, the minimum height of the center of the entrance pupil is about 0.150 in. above the model surface. Table 5-3 shows the real-world height to which this corresponds at various scale factors. On ground, the pilot's eye height in the AH-64 is about nine feet from the ground. Thus the minimum scale in which a landing could be performed is about 750:1. Larger scales would provide greater ground clearance and would be safer. Smaller scales would not permit landings to be performed.

As discussed in paragraph 5.8 (probes) the depth of field in the scene depends on the type of probe selected and the height above the model of the entrance pupil. For tilt-corrected probe, the closer the probe gets to the model surface, the greater the tilt required and the more restricted the vertical depth of focus. For a non-tilt probe, the depth of focus is fixed by the aperture and focus point. However, the closer the probe is to the model surface, the greater the area of out-of-focus detail in the foreground FOV. So it is preferable to keep the on-ground height of

TABLE 5-3. VARIOUS MODEL PARAMETERS VS. SCALE FACTOR

Model Parameter	250:1	500:1	750:1	1000:1
Model Detail (Min. @ 0.012 in.)	3 in.	6 in.	9 in.	12 in.
Speed @ 60 KTS	4.8 in/sec.	2.4 in/sec.	1.6 in/sec.	1.2 in/sec.
Clearance @ 25 Ft.	1.2 in.	0.6 in.	0.4 in.	0.3 in.
Min. Probe Ht. (@ 0.15 in.)	3.1 ft.	6.3 ft.	9.4 ft.	12.5 ft.
Safety Grid Required (@ 50 ms.)	0.5 in.	0.5 in.	0.25 in.	0.25 in.
X Stop Acceleration	-5.6 in/sec.^{2}	-2.8 in/sec.^{2}	-1.9 in/sec.^{2}	-1.4 in/sec.^{2}

the entrance pupil as far from the model surface as possible. Therefore, a scale of 750:1 would be the worst scale at which landings could be performed. Scales of 500:1 of larger would improve on-ground focus. Optimum scale selection would depend upon the focus distance and aperture of the probe and the downward FOV to be displayed. From our experience with the CH-47C visual system using a non-tilt probe and programmed scales of 250:1, 500:1, and 750:1 with a 20^{o} downward FOV, 500:1 is the minimum recommended scale.

5.9.2.4 Safety System. A safety system must be employed with contoured model boards to prevent the optical probe from hitting the model surface during training maneuvers. This is particularly important in NOE helicopter applications, where the pilot is attempting to fly at high speed and as close as possible to the ground. Two methods are available for protecting the probe: hardware and software.

Hardware protection is provided by placing appropriate transducers or sensing elements around the probe to detect unsafe conditions. In designing the CH-47C visual system for the Imperial Iranian Army, CAE conducted a study of hardware sensing devices. Contact and noncontact sensors studied included:

. Inductive devices

. Capacitive devices

. Pneumatic devices

. Infrared light sensors

. Spinning wires

. Micro switches

. Strain transducers

. Frangible wires

. Linear transducers

None was able to provide an accurate, repeatable indication of distance to the model of less than 0.020 inch in any of the three axes without interfering with the FOV, pitch, or heading assemblies of the probe. Therefore, a software safety system was developed for protection of the probe when the system is under computer control, coupled with a hardware logic safety system for protection in the off-line, or manual operating mode. The system has proved to be entirely satisfactory, and no damage has been done to date with the software safety program operating.

The software safety system is based upon having a digitized representation of the model surface stored on the host computer disc. This data base must be sufficiently accurate so that the model surface calculated from it at any point on the model must deviate from the true value by no more than the minimum probe clearance at that point. The data base is in the form of a grid, where the intersection of any two lines defines a measured point and intermediate values are interpolated. There are three possible sources of error in this system.

The first is the accuracy of the measured surface contour. Using a 16-bit encoder, measurement accuracy is better than 0.001 inch over a 2-foot travel.

The second is due to surface variations between measured reference points. For contoured slopes of maximum angle D and grid spacing x, the worst case static error is given as shown in Equation (5-1).

$$E_s = \pm \frac{\sqrt{2}}{2} x \tan D \tag{5-1}$$

For gently rolling but smooth surface contours of maximum slope D, E_s becomes a function of the grid spacing.

The third source of error is due to the sampling effect of the computer iteration rate. Since the surface calculation is done only during the program iteration and the probe moves between iterations, this movement generates a dynamic error. For a given iteration period t, a given probe velocity V, and a maximum contour slope D, the dynamic error is that shown in Equation (5-2).

$$E_D = \pm \sqrt{2}\,(Vt) \tan D \tag{5-2}$$

For a maximum slope D, this error becomes a function of the iteration rate of the computer and the probe velocity, which is a function of the model scale. For maximum slopes of 30°, and assuming a typical speed of 60 knots at 25 feet altitude, the recommended maximum grid spacings are given in Table 5-3. Since a 24-by 76-foot model requires about four million points to be measured at a 0.25-inch grid spacing, it is preferable to use larger scales to increase grid spacing and minimize the number of data points. During flight, once the safety system has detected an unsafe condition, it must be capable of bringing the system to a halt before any damage is done. This requires a certain minimum deceleration to stop the system within the safety limit. For the worst case of flight at 60 knots towards a 30° slope, the required X axis stopping acceleration (minimum) is given in Table 5-3. As can be seen, the required deceleration increases rapidly with increasing scale.

The safety system clearly demands compromises. At scales greater than 500:1, the stopping accelerations become large. At scales smaller than 1000:1, maximum grid spacings become too small to measure easily. Thus a scale of 750:1 is the best compromise for the design of the safety system.

5.9.2.5 Summary of Model Scale. From the preceding discussion it is evident that no one scale will satisfy all the requirements. The best that can be done is to rule out totally unacceptable scales. Table 5-4 is a summary of the results of the previous discussions. It can be seen that the only scales that are at all acceptable are 500:1 and 750:1 (and, of course, scales in between). A scale of 1000:1 will not permit landings in the simulator (an unacceptable restriction) and will suffer from restricted focusing even at NOE altitudes. Scales of the order of 250:1 offer completely unacceptable playing areas and require large decelerations for the safety system. However, neither of the acceptable scales offers sufficient playing area, although 750:1 is almost adequate. The 500:1 scale offers better detail and probe clearance but requires larger safety stopping distances. Thus the final choice of scale must depend upon the weighting placed on individual factors.

TABLE 5-4. SUMMARY OF MODEL SCALE RESULTS

Scale	Playing Area	Detail	Probe Clearance and Focus	Safety System
250:1	N.A	G	G	P
500:1	P	G	G	A
750:1	P	A	A	G
1000:1	A	A	N.A	A

G GOOD
A ADEQUATE
P POOR
N.A NOT ACCEPTABLE

5.9.2.6 Model Surround. One of the most apparent problems of the terrain model board is the ability of the pilot to see beyond the edges of the model. These edges are normally hidden in one of three ways.

First, a plain blue or white background can be placed around the model. This simulates sky or cloud in a fairly realistic way over most of the model, but the effect rapidly deteriorates as one flies close to the model boundary and loses the horizon reference. Furthermore, only at certain positions and headings is the horizon reference correct. Elsewhere it is below the true horizon, giving a false cue to the pilot.

Another possibility is to make the model in the form of a valley, where hills or mountains around the perimeter obscure the pilot's view of the horizon. This works well, providing the modelled terrain suits such an arrangement. However, it does tend to generate a feeling of confinement in a small playing area.

The normal method used is to surround the model board with plane mirrors which, by reflecting the model itself, give the effect of a larger landscape fading off into the distance. Several types of mirrors can be used. Ordinary glass rear surface mirrors are cheap and of high quality, but in butting panels to cover a 76-foot side, large gaps appear in the reflected images because of internal reflection at the mirror edges. Front surface mirrors are more expensive, but since the coating is on the front of the glass, no internal reflection occurs at the edges. All that can be seen is a hairline joint between mirror panels. These mirrors require more care in handling and cleaning than rear surface ones.

The third type of edge mirror is made of aluminized mylar film stretched over a frame. If the frame is well designed, the mylar can be adjusted to give a smooth, flat, good quality reflective surface. However, with age, and particularly under high ambient lighting containing appreciable ultraviolet radiation such as that used for the CCTV system, the mylar will degrade. It can sag and becomes brittle with age. Being a front surface reflector, it is more difficult to clean. However, when this aging occurs, it is possible to simply replace the aluminized mylar film. The film itself is not very expensive and the change can be made quite rapidly. For a large surface area, mirrors of aluminized mylar are probably the most cost-effective product to use.

There are two disadvantages with the mirror system. First, in some situations it is possible for the pilot to see reflections of the probe in the mirrors. This can be minimized by using reduced vertical travel and by careful design of the model contours near the mirrors. Electronic keying can sometimes be used to key out the image of the probe above the horizon.

The second disadvantage is that when pilots can see a continuing landscape, they try to fly over it and thus into the mirrors. The system is commonly programmed to stop the probe and insert cloud when the aircraft approaches the model edge, but pilots find this sudden transition a disturbing shock (Ref. 5-10). A way must be found to prevent the pilot from wanting to fly off the edge.

For the AH-64 simulator a ready solution is evident. Since the primary mission of the helicopter is to engage enemy tanks and threat vehicles from a distance of at least 3 km, these threat vehicles can be inserted into the reflected terrain beyond the model edge, using special effects (muzzle flashes) and CGI techniques (TADS). The pilot may then engage the targets from inside the model board. If we assume that the mirrors extend the model dimensions by 3 to 4 km on each side, the playing area of a terrain model becomes sufficient even at larger scales. At a scale of 750:1, this has the effect of at least tripling the playing area. Since the pilot will be entering within enemy firing range should he go beyond the mirrors, he will be hesitant to do so. Furthermore, the landscape can be made to afford camouflage near the model edge with an open exposed area beyond to further discourage the pilot. Planned missions will also alleviate the problems.

When mirrors are used, it is general practice to insert sky and cloud conditions electronically. These can be inserted down to the horizon line. However, when trees or hills project above the horizon, they will be cut off. Electronic keying can be used to insert these features, but it is extremely difficult to design a system that will work well with objects of various shapes, colors, and brightnesses. A preferred alternative is to place a blue or white 'surround' extending a foot or so above the mirrors. Model features will appear realistically silhouetted against this background. Beyond the surround sky can be electronically inserted with no problem. The computer can be used to calculate the position of the top of the surround and to insert sky starting at that point. The only disadvantage with this system is that the sky can only be one color for daylight simulation. Fog and other effects remain unaffected.

5.9.3 Model Construction. To obtain the greatest playing area, the largest practical model board should be built. As previously discussed, a 24-by 76-foot model is probably the best size. Large models are best made from a set of smaller panels. A fairly standard size for these panels is 4 by 8 feet, so that a 24-by 76 foot model would be composed of 57 panels.

Ref.5-10. Hutton, D., Englehart, J., Wilson, J., Ramaglea, F., and Schneider, A., Air-to-Ground Visual Simulation Demonstration, Project 2235, ASO SIM/SPO, Wright-Patterson AFB, Ohio, October 1976.

A panel of this size is easy to handle both in the modelling phase and the assembly phase. Such panels can be cast in fiberglass, providing a strong, rigid panel of moderate expansion coefficient that will not rust, warp, or rot. Contours can be applied to the surface by molding the fiberglass directly or by applying a layer of low density polyurethane foam. Though molding the fiberglass directly is cheaper and better for producing matched models, the addition of several inches of a low density contouring foam has some advantages. Besides being easier to work with and to attach objects to, a soft low density foam can provide a certain safety margin by absorbing a probe impact and cushioning the probe tip in the event of a system failure. A rigid fiberglass panel would destroy the probe tip under similar conditions. Polyurethane foam is easy to repair and can be recontoured if so desired. Furthermore, experience with such models has demonstrated that foam panels on a fiberglass base tend to absorb small deformations due to handling and mounting of the panels, thus preventing cracking of the surface paint. However, care must be taken to cure the foam and the foam fiberglass bond thoroughly before paint is applied.

Another technique, which has been developed by John Piper Ltd., is to use a contouring material made of pulverized fuel ash and resin. This material is hard when set, but can be easily molded and worked while fresh. It is highly stable dimensionally, very light, and more fire resistant than polyurethane foam. It is, however, very brittle. This technique is best suited to models requiring high dimensional stability under varying temperature/humidity conditions.

Other potential materials are wood, aluminum, and other plastic foams. Wood is not fireproof and can shrink, warp, and crack with varying temperature and humidity. Aluminum, while light and strong, has a high expansion coefficient and is somewhat costly. Other plastic foams and materials have been tested by CAE and found to be wanting in one or more of the following areas.

- Poor dimensional stability
- Strong humidity effects
- Poor workability
- Poor paint adhesion
- Limited lifetime
- Insufficient strength and rigidity

The paint used on a visual system terrain model must exhibit several important properties. First, it must be very fine grained and nonspecular at high angles of incidence. Second, it must be stable against cracking, peeling, or color changes during long periods of use under high

ambient illumination. Third, it must exhibit high reflectivity and good color balance to provide an optimum input for the TV camera used in the system. During the past six years, CAE has undertaken several studies of model paints and lighting (Project E184 and TPD 6179) and would recommend the use of selected Floguil 'Poly S' model paints on a high reflectance white primer undercoat. These paints meet all of the above requirements and have been used very successfully on our CH-47C visual system. The model maker for that project, John Piper Ltd., has since adopted these paints as his standard.

Because of the nature of the maneuvers to be performed by the AH-64, it will be necessary to ensure that all surface features added to the model, such as trees, buildings, vehicles, etc., are frangible to the extent that they deform harmlessly or fall off when impacted by the probe.

5.9.4 Model Lighting. In the following discussion, refer to Figure 5-14 through 5-20. The lighting bank is an integral part of the design of the model/CCTV system. Since the model surface is illuminated by the lighting bank, the light detected by the TV camera depends upon both the reflectance of the paint and the emission spectra from the lamps. A fact that is often overlooked is that the TV camera is a much more demanding observer than the human eye. A light that looks white to our eye may look yellow, pink, or green to the color TV system. Furthermore, a red reflecting paint of a certain hue looks red by selectively reflecting light of that hue. If the illuminating source is composed of discrete emission lines, as in the case of mercury or metal halide lamps, that particular hue may not appear at all. Thus the lighting bank must be chosen to have a broad and rich color spectrum, containing red, blue, and green light in roughly equal quantities.

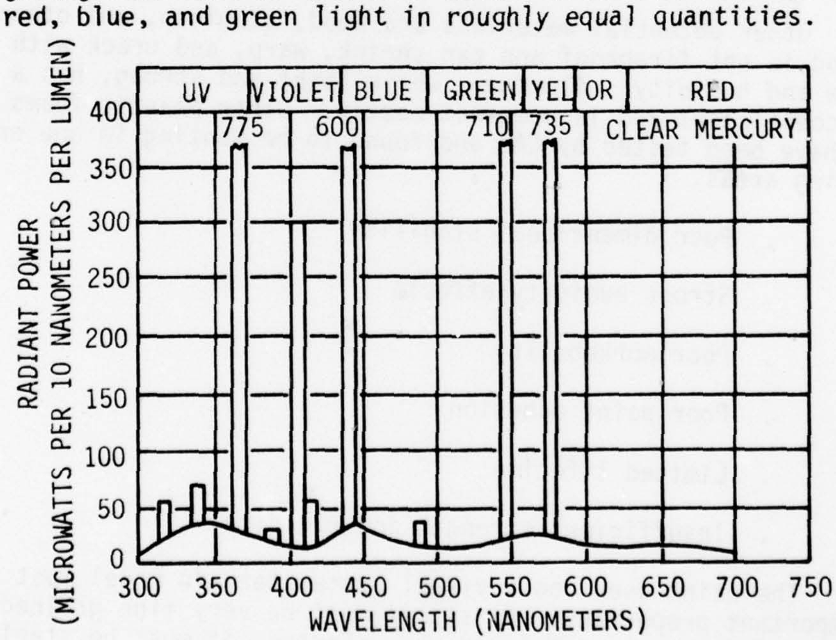


Figure 5-14. Emission Spectrum of Clear Mercury Lamps

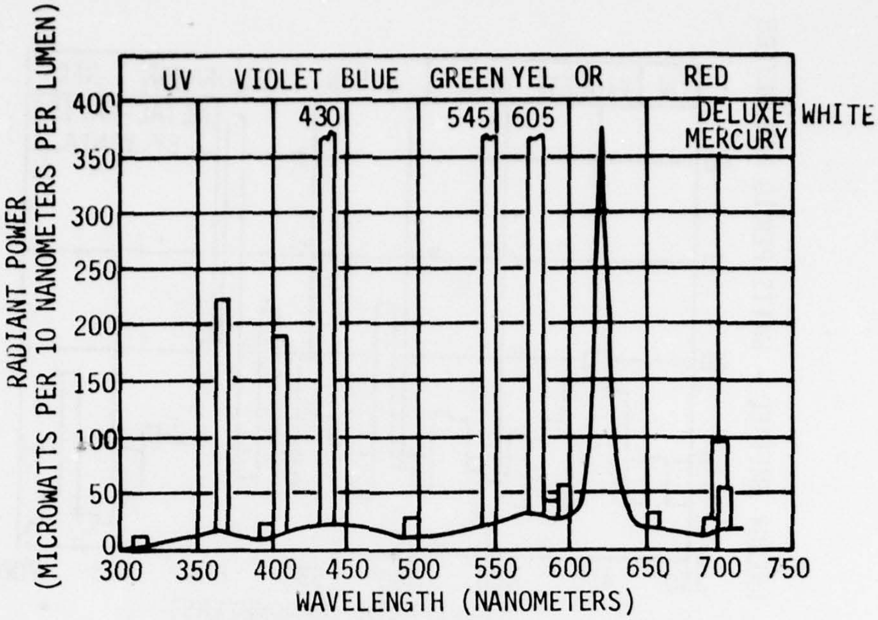
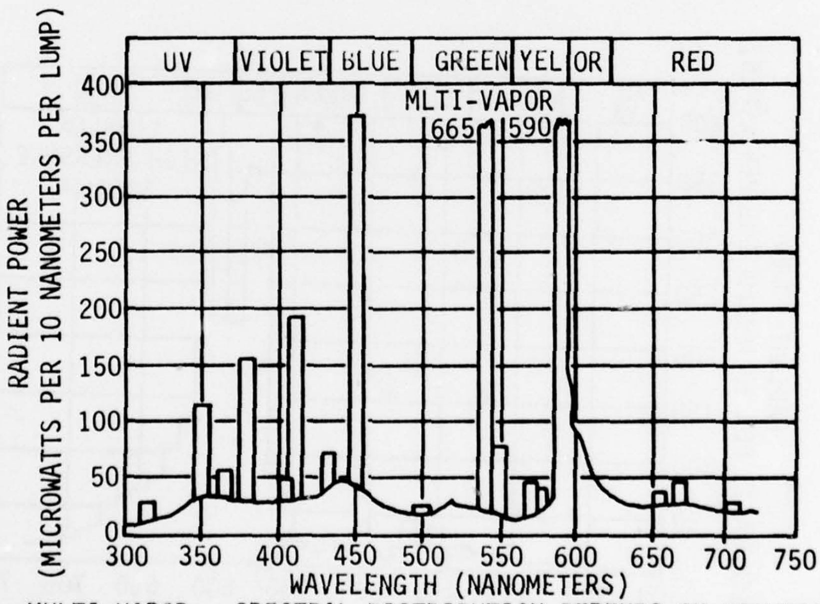
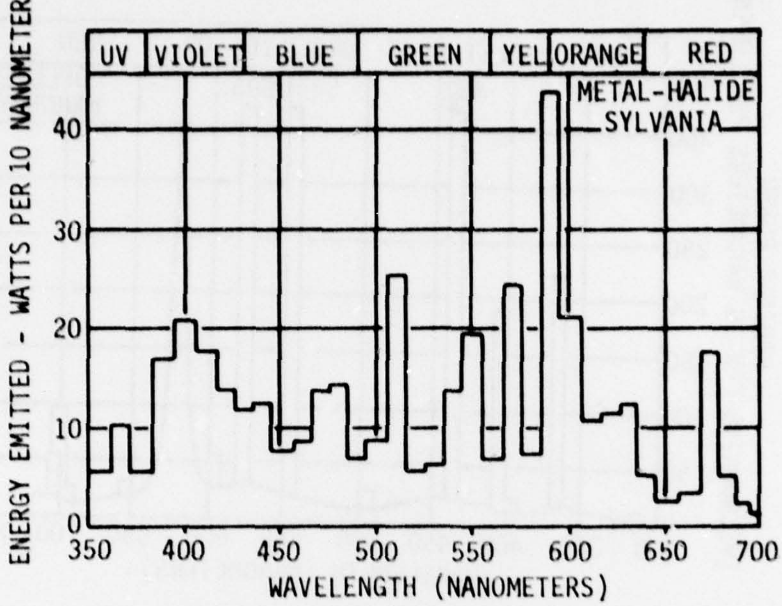


Figure 5-15. Emission Spectrum of Deluxe Mercury Lamps



MULTI-VAPOR: SPECTRAL DISTRIBUTION DEPENDS ON MANUFACTURER

Figure 5-16. Emission Spectrum of Multi-Vapor Lamps



SPECTRAL ENERGY DISTRIBUTION OF 1000-WATT METALARC CLEAR LAMP

Figure 5-17. Emission Spectrum of Metallic Halide Lamps

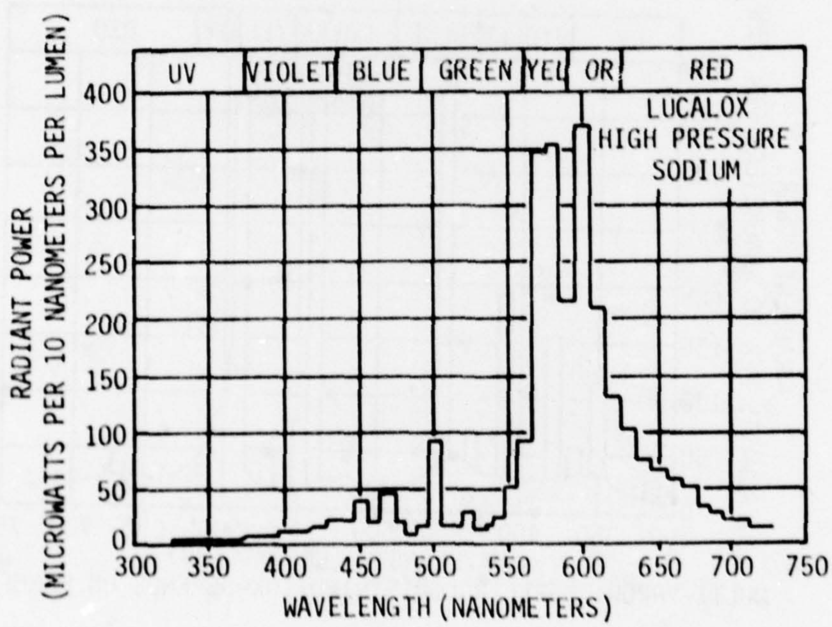


Figure 5-18. Emission Spectrum of High Pressure Sodium Lamps

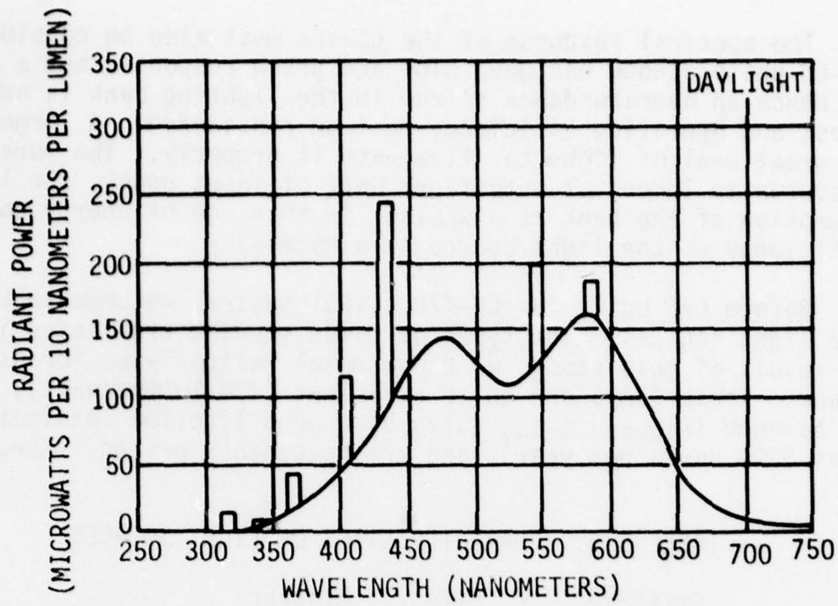


Figure 5-19. Emission Spectrum of Fluorescent Daylight Lamps

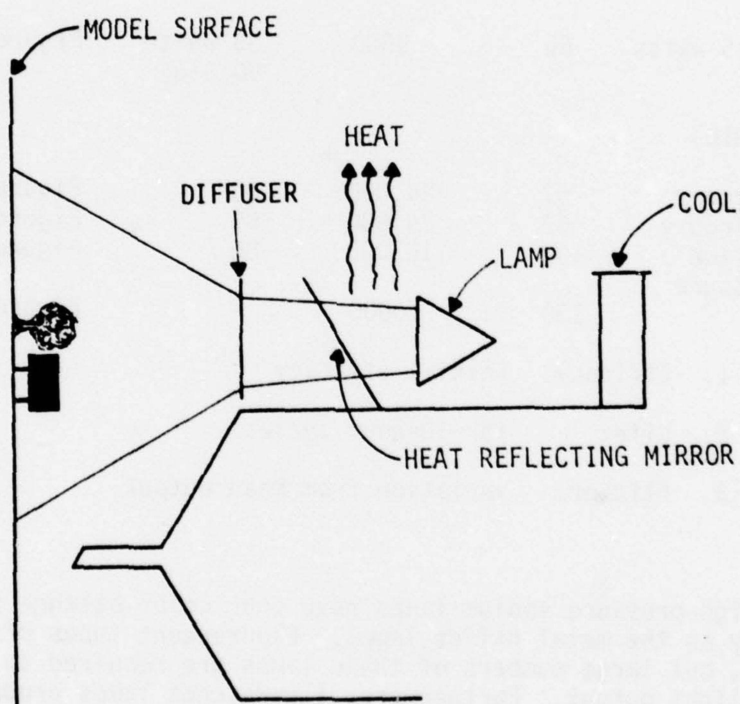


Figure 5-20. Probe Lighting System Utilizing Quartzline Lamps

The spectral response of the camera must also be considered. The standard S-20 photocathode has good blue and green response, but a poor red response. Hence an overabundance of red in the lighting bank is advantageous. Finally, cost and operating efficiency must be considered. A large model requires a great deal of light to illuminate it properly. The more efficient the light source in lumens of output per watt of input power, the lower the power consumption of the bank as a whole. In this age of energy conservation, maximum efficiency of the light source is a necessity.

Before CAE built the CH-47C visual system, we undertook a study of possible light sources. The types of lamps studied are listed in Table 5-5. As a result of this study, we chose metal halide lamps for use in our lighting bank. These lamps are quite efficient (100 lumens/watt), exhibit a good color balance (Figures 5-16, 5-17) have good lifetime (estimated two years at 5000 hours per year), and are reasonably priced. Mercury arc

TABLE 5-5. CHARACTERISTICS OF LIGHT SOURCES

Light Source	Efficacy[1] (lumens/watt)	Life[2] (hours)	Flicker (%)	Spectral Distribution
Incandescent	20	1000	2	black body radiation
Fluorescent Daylight, 215 watts	60	9000	35 white 90 blue	Figure 5-19
Discharge (HID)				
- Clear mercury	57	24,000	80	Figure 5-14
- Deluxe mercury	62	24,000	80	Figure 5-15
- Metal Halide	100	10,000	80	Figures 5-16, 5-17
- High pressure sodium	130	10000	-	Figure 5-18

1. Efficacy: initial efficacy
2. Life: for 10-hour cycles
3. Flicker: variation from mean output

lamps and high-pressure sodium lamps have poor color balance for about the same economy as the metal halide lamps. Fluorescent tubes offer a cheaper alternative, but large numbers of these lamps are required to produce sufficient light output. Furthermore, fluorescent lamps produce a very diffuse light that cannot easily be controlled. For CCTV visual systems we

have found it essential to be able to control the lighting to produce shadow effects and to sidelight objects such as trees, buildings, and vehicles. Without this sidelighting, colors and detail become washed out and disappear on maneuvers close to the ground (Ref.5-11). Thus we recommend adjustable arrays of moderate beamspread fixtures, each employing one 1000-watt lamp. As a further refinement, we studied various brands of metal halide lamps (Thorn, GE, Sylvania, Philips, Westinghouse). We found the best color spectra to be produced by the Thorn Atlas or the Sylvania Metalarc lamps.

A problem in all terrain model board systems is the shadow cast by the probe when close to the model surface. This shadow is readily apparent through the TV chain and must be eliminated by placing supplementary lighting around the probe. This lighting must be compact, high brightness, diffuse, and must closely approximate the main lighting bank in color content. It must also be 'cool', that is, the probe lighting must not heat the probe tip or model surface excessively.

We have found that the best way to achieve good probe lighting is to use standard quartzline projection lamps in conjunction with ground glass diffusers and heat reflecting mirrors. This is shown in Figure 5-20. The heat reflecting mirror both reflects the heat and modifies the spectral output of the lamp to produce a close match to the color of the lighting bank. Light output is high, and eight overlapping lamps provide a uniform distribution around the probe tip.

5.9.5 Recommendations. From a consideration of the preceding sections, it is apparent that no one model will meet all of the training requirements for the AAH. Selection of any specific scale factor must depend on the assignment of priorities. From our experience, good model detail and on-ground focussing performance are essential to the success of a CCTV/model board system. Playing area, while important, must take second place to picture quality. Thus we would recommend a model scale of 500:1. This scale provides the following:

- Good model detail
- Sufficient probe clearance for good on-ground focus
- Has acceptable stopping acceleration requirements
- Requires 1/4 as many data points to be measured as a 750:1 scale (refer to Table 5-2).

Ref. 5-11. Putman, R., Wiggin, J., Clark, C., and Williams, H., Discharge Lamps and Color TV, 4th Annual Theatre, TV, and Film Lighting Symposium, New York, 1968.

Identifiable target vehicles can be easily modelled in this scale, and good trees and texture produced.

The basic playing area for a 24-x 76-foot model at 500:1 is 3.7 x 11.6 km, which does not by itself meet the criteria for an adequate playing area. However, if we install mirrors around the model and insert our targets into the mirror image, we can extend the effective tactical playing area by about 4 km on each side of the model, quintupling the total area (Table 5-6) A typical layout is shown in Figure 5-21. The actual model or flight area contains the staging field, NOE terrain, and hidden targets. Using an indirect route, the pilot can fly a 10-to 20-km NOE course to the forward attack position. From there, looking into the terrain extension in the mirror, he can see threat weapons discharges generated by the special effects electronics. The copilot/gunner looking in this TADS will see CGI-generated threat vehicles as though the model continued beyond the mirrors. Engagements can be fought from this position with full simulation capability, including moving vehicles.

TABLE 5-6. PLAYING AREA VS. SCALE FOR 24 X 76 FT. MODEL (WITHOUT MIRRORS AND WITH MIRRORS ADDING 4 KM/PER SIDE)

Scale	Playing Area (No Mirrors)	Playing Area (+4 km/side)
500:1	3.7 x 11.6 km.	11.7 x 19.6 km.
750:1	5.5 x 17.4 km.	13.5 x 25.4 km.

Since the AH-64 will perform its most important maneuvers at altitudes of less than 200 feet, we propose limiting the vertical travel to six inches, the equivalent of 250 feet. In this way we require only six inches of mirror around the model, which reduces the problem of the pilots seeing a reflected probe image. A white surround extending for 2 feet above the mirror will allow objects to silhouette against a sky, and electronic keying would extend above this backdrop. For this system we would recommend the use of front surface glass mirrors, since the quality of the mirror image is an important element in the system.

With an AOI approach, it is not possible to get both pilot and copilot/gunner pictures from the same probe. Thus two model board systems will be required, each with its own probe and camera. Since the AH-64 simulator(s) may be used for combined mission training, both models must be the same. Since the AH-64 flies close to the ground terrain features must be accurately positioned in both models. Over a large area it is feasible to have identical features corresponding within 1 mm of each other. This corresponds to a 0.5 m displacement between objects seen by both pilots, which is quite tolerable.

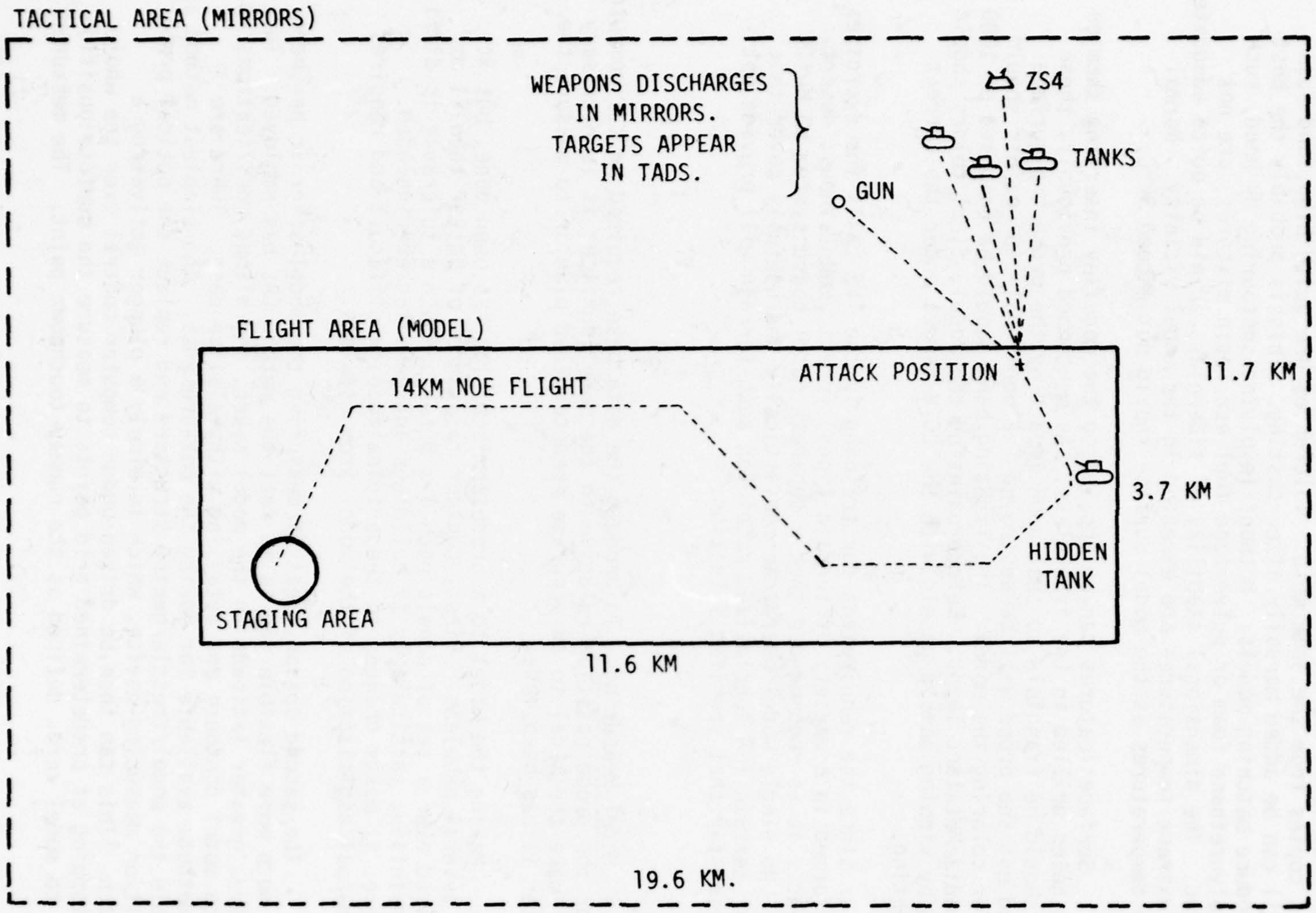


Figure 5-21 Typical Expanded Model Board, 24 ft. x 76 ft., 500:1

The usual way to produce identical models is to cast multiple fiberglass copies from the same mold. Tolerances are quite high, and surface detail can be added manually after casting. This is probably the best way to produce matching models. Methods involving contouring by hand, such as with polyurethane foam or pulverized fuel ash resin mixtures, are not recommended. The dimensional stability of fiberglass should be quite adequate since no extreme temperatures are expected in the model vicinity. Normal operating temperatures at the model surface should not exceed 38°C.

Surface features can be applied to the model by inserting them on pegs into holes drilled in the fiberglass. As mentioned previously, these features should be frangible so that upon impact by the probe the surface detail and not the probe will be destroyed. Floquil Poly 'S' paints should be used for coloring the model. The lighting bank should be composed of 1000 watt Sylvania Metalarc lamps. Before painting the model, final colors should be chosen by viewing sample panels with the CCTV camera under the correct model lighting.

Since the requirement for training in the FWS calls for exercises to be performed in a variety of terrain types, forest, mountainous, desert, arctic, etc., it is recommended that a separate model board system be built for each. No single model board can realistically and usefully cover this variety of terrain. A specialized model for each terrain will provide optimum training for that specific situation.

5.9.6 Model Measuring. To produce the data base required by the computer to monitor the probe position relative to the model surface, it is necessary to either make the model to an accurate predetermined plan or to measure the model after it has been made.

Making the model to a predetermined plan has been done, but it involves several problems. First, contour tolerances of better than ±1 mm are required over a set of panels each 4 x 8 feet. Such a tolerance is difficult to maintain, particularly if buildings and vehicles are included. Furthermore, it makes changes to the original design difficult and requires tedious manual digitization of the model from drawings.

The second option, that of measuring the model after it has been made, is much more flexible and is in fact the method CAE has employed. This method gives greater latitude to the model maker, and allows modifications to be made to model contours and detailing with relative ease. There are several methods available for making the measurements. The simplest method is to assemble the model/trestle/gantry structure and replace the optical probe by a position measuring device, which is simply a plunger activating a microswitch. This can then be driven under computer control over the whole model, stopping at predetermined grid points to measure the surface position relative to model zero, defined as the runway touchdown point. The measured

positions are automatically stored in the data file, and a printout is produced for further reference. Such a system is completely automatic and results in a uniformly accurate data base. The only disadvantage in this method is the time required to take the measurement. It is not possible to measure reliably at a rate faster than about one point every 15 seconds. Such a system can be employed for a small model or a large grid spacing. However, measuring a large model with high detail is impractical because of the time involved.

Several alternate methods of measuring the model have been studied such as laser ranging or using arrays of linear transducers. At present there is no suitable laser or interferometric device available. An array of linear sensors, employed instead of a single plunger in the first system, would drastically reduce the measuring time but at a slight loss of accuracy. This is because of the difficulty of matching two or more linear position transducer responses. This sytem would, however, be the cheapest and simplest alternative. Another mothod is to use a modification of aerial mapping techniques and take stereo photographs of the model, panel by panel. These photographs can be automatically processed to yield a surface contour data base of reasonable accuracy, but at a very high cost. This method produces accurate topographic maps of the model as a byproduct.

A complication arises when it is necessary to include objects in the data base such as buildings and vehicles, yet exclude trees for one part of the training task and include all obstructions for other tasks, such as target detection and ranging. To do this properly requires making two sets of measurements, one without frangible detail and one with. Alternatively, one set of measurements could be made and all additional objects added to the data base manually. This would be very tedious if large numbers of additions are necessary.

No matter which method is used to measure the model, provision must be made for manual corrections and adjustments to the data base. These are sometimes necessary to correct measuring errors or to enhance contours around particularly dangerous model features. At the same time, sufficient protection of the data base must exist to prevent accidental changes or changes made by unauthorized personnel.

5.9.7 Gantry/Servos. In a CCTV/model board system, the design of the trestle and gantry is of great concern. Since the CCTV camera and optical probe are carried on the gantry, it must exhibit smooth step-free response, good dynamic range, and freedom from vibration or oscillations under normal 'flying' conditions. At the same time, the gantry must not cast a shadow across the model because of its position between the model and lighting bank. The trestle supporting the model should be as simple as possible, yet strong enough to prevent any sag or shifting of the model panels. Free access to both sides of the model panels is required for mounting and aligning and for installation of runway lights if required. Servo systems used

to move the gantry must be capable of a wide dynamic range and precise positioning without jitter or 'hunting'. CAE has built several gantry/trestle systems and has studied many possible designs. We have also had discussions with other simulator manufacturers regarding their experience in gantry/servo design and have visited many simulator sites to observe the various solutions of other manufacturers to the common problems.

5.9.7.1 Trestle. Several trestle designs have been tried: vertical, inclined, and horizontal. Of these, the vertical mounted structure offers the simplest access to both sides of the model. At the same time, a vertically mounted lighting bank offers an advantage in that it is somewhat self-cooling by convection. Touchup work on the model is also easier to perform on a vertical structure than on a horizontal one, and dust collection is less of a problem. Hence a vertical design, preferably a light rigid frame, is the most suitable structure. Individual model panels of reasonable size (4 by 8 feet) can be bolted to this frame with little difficulty to provide a large playing area. Furthermore, by divorcing the gantry support from the trestle in a vertical design, it becomes possible to vary 'Z' travel limits and accommodate various types of terrain from flat desert to rugged mountains. The trestle should include a ladder and platform to allow access to the back and top of the structure.

5.9.7.2 Gantry. Two basic gantry designs have been tried to date: a thin rigid column mounted on a wide base and a wide open-framework tower. The single column offers a low cross section to prevent shadowing of the model, but it must be stabilized at the top to prevent whiplash as it moves. The best method is to drive it at top and bottom simultaneously, but absolute motor synchronization and a positive drive system are necessary. Since it is a single rigid bar, oscillations sometimes become a problem. The open lattice girder type gantry limits shadowing by its very openness. If this is not sufficient, it is possible to mount supplementary lighting within the framework. This type of gantry can be made very rigid and can be driven from the base without significant whiplash. However, a stabiliser bar may be necessary to prevent small oscillations. The open gantry structure allows free access to all drive systems and video components. The gantry should be mounted on linear bearings on parallel ground bars to provide optimum stability and smooth response. Our preference is for the open lattice girder type structure because of its superior stability and ease of maintenance access.

The 'Y' carriage, together with the counterweight, should be mounted one on each side of the structure on parallel ground bars, utilizing linear bearings. The 'Z' table assembly can be mounted on a single ground bar with a stabilizing wheel or on two parallel ground bars as for the other axes.

5.9.7.3 Drive Systems. The drive of the gantry can be designed in several ways. These are:

. Friction drive wheel

. Rack and pinion drive

. Cable drive

. Ball and screw drive

. Chain drive

A rack and pinion drive is the most suitable for the 'X' axis. It provides direct positive traction for fast acceleration and quick stops in emergency situations and is easy to use over a large distance. The positioning accuracy is high.

A rack and pinion or chain drive can be used for the 'Y' drive. Over limited distances, both of these methods offer precise, smooth positioning and both can be used easily in a vertical situation. Since the 'Y' carriage must be counterbalanced, which can easily be done via the drive chain, this system may prove simpler.

The 'Z' drive requires smooth performance at low speeds and over short distances. The positioning accuracy must be extremely high, with no backlash. For this a ball and screw drive is best.

The gantry motor drives can be either conventional analog servos or digital stepping motors. CAE has employed both systems, and for the wide dynamic range of helicopter flight (0.02 knot to 200 knots) we have found the digital motors to be superior. Furthermore, the digital motors are simpler to drive from a computer and exhibit high torque in a small package size. The main disadvantage of stepping motors results from their sensitivity to the inertia of the load they are driving, often producing resonance effects between the load and the motor at select speeds. Our experience has shown that careful design of the motor/drive system, taking into account the inertial load on the motor, can eliminate this problem. We have found the use of oversize motors to be advantageous.

The electrical cabling to the gantry is carried in a separate cable track running parallel to the 'X' axis. Our experience has shown that it is best to drive this independently of the gantry, but in synchronism with the 'X' servomotor. This prevents any of the inherent jerkiness of the cable track movement from affecting the gantry tower.

5.10 CGI SYSTEMS

5.10.1 General. During the initial analysis of the AH-64 training requirements, CGI (Computer Generated Image) seemed totally inadequate and a model board approach was considered to be the only solution. However, as the details of the TADS unfolded, it became quite apparent that a model board approach by itself was unable to cope with the total simulation. It was realized that CGI had to be used for the TADS, and it was decided to put a significant effort into CGI systems to see if it was at all possible to use CGI for the main visual scene as well.

It was known that GE was developing textured CGI scenes, which seemed to be the only way that NOE flight over reasonably large areas could be accomplished. However, before a visit to GE could be arranged, we were invited to a demonstration of CGI having texture by Marconi in England. Although Marconi had only a breadboard system working, the pictures we were shown on a CRT included textured fields, trees, clouds, buildings, etc., and gave a far greater sense of depth and solidity than other CGI systems not having texture. The texture can apparently be defined mathematically, so that finer levels of texture appear as the surface moves closer to the observer. The texture is processed in the same way as the surfaces and is firmly 'attached' to its surface under all dynamic conditions. Texture can also be used to apply regular patterns to surfaces such as bricks on a railway bridge or the sleepers under the tracks. Marconi was reluctant to disclose details of its process, but its results are of high quality.

In a subsequent visit to GE in Daytona, we were shown textured surfaces on simple geometric shapes which, although impressive were not as realistic as on the Marconi system. GE generate a series of lines having variable spacing and orientation which it can apply to any surface in a way similar to that used in the Marconi system. This approach, though it improves the perception of depth in a scene, does not seem to be as flexible as the pseudo random pattern approach of Marconi, which can be applied equally well to clouds, vegetation, and manmade objects.

5.10.2 Data Base Complexity. The use of texture considerably reduces the need for large numbers of faces in a scene. Most of the Marconi photographs have less than 500 faces, and it would appear that 1000 textured faces are quite adequate for a $40 \times 50^{\circ}$ field of view. This is an important consideration when one realizes how many faces or edges are required to create an area of only one square kilometer. One hundred thousand faces spread over one square kilometer represents an average density of one face in 10 square meters. If we consider a helicopter hovering at an eye height of 15 feet, we find that the area enclosed by the lower part of the scene, i.e., between 15 degrees and 30 degrees below the horizon is about 50 square meters for a 40-degree horizontal sector.

Five faces would, therefore, make up the average scene content in this part of the picture. With texture this is probably adequate, but without texture a pilot could have considerable difficulty judging his height.

The figure of 100,000 faces was suggested by GE and it would appear to be adequate. Several million faces would be necessary to describe a large area, and the problem of generating such a data base is considerable. GE has a novel approach in that it models the large area at a relatively low density and unrolls a comparatively small, highly detailed area in front of the helicopter as if it were a carpet. The carpet detail would repeat at regular intervals but be superimposed on the contours of the simple data base. The NOE flight would have to be restricted in altitude so that the edge of the carpet was not apparent, and this might impose unwanted restrictions on the maximum contours of the data base. Marconi takes the view that mass storage devices are inexpensive and that it is better to have the whole model at high detail, with which we tend to agree; however, it would still be possible to use repeating parts of the model to alleviate the data base generation problem. Marconi also uses nested data bases, which allows the entire model to be described by a low-level data base that is replaced by successively more detailed data bases as the observer moves towards the area in question. An example of this would be a grove of trees which at a distance from the observer's viewpoint would be defined by a data cluster of a few colored faces. More detailed clusters in the data base library would show the grove as an object with many more faces and finally as individual trees.

The modelling of trees presents a problem and Marconi made a remarkably realistic tree which we feel would give strong parallax cues as one moved around or towards it. Many faces are necessary to describe it so that only a few could appear in the scene at any one time. Other CGI manufacturers with whom we have been in contact think more in terms of single shapes, such as cones and dodecahedrons with straight trunks.

5.10.3 Edge Smoothing. Edge smoothing in both horizontal and vertical dimensions is important to obtain smooth movement of the scene. Marconi uses eight levels of weighting to move an object across the raster or along the raster. GE has an edge smoothing system, but it only seems to work in the horizontal direction. Redifon has both edge smoothing and something they call an 'anti-aliasing algorithm'. Biberman and Schade have written about the dangers of aliasing for many years (Ref. 5-12) and it is pleasant to see that CGI manufacturers regard the problem in a similar light.

Ref. 5-12. Perception of Display Information, ed. L.M. Biberman, Plenum Press, New York, 1973.

5.10.4 Other Considerations. Stereo techniques seemed to offer a way of giving the pilot more depth cues and were studied in detail. However, they would appear to be of limited usefulness. The results of the study are given in paragraph 5.11.

GE and Marconi were the only companies visited during this study and we believe they are the only ones offering textured surfaces. We are firmly convinced that no system without texture can offer adequate cues for NOE flight and we believe that both Singer and Evans and Sutherland Redifon are working in this area. From what we have seen of the GE and Marconi systems it would appear that the Marconi system offers the best picture but does not have a full working system and will not until late 1978. GE has a proven production record although its texture generator is developmental. Since CGI features in the model board approach as well, it will be necessary to ascertain Marconi's ability to produce a fully working system in the available time scale.

5.11 STEREO VISION TECHNIQUES

5.11.1 Advantages of Stereo. The primary application for stereo was its adaption to a CGI visual system to enhance depth cues encountered in NOE flight. The main concern expressed about CGI systems in general is lack of details: specifically, the complete lack of texture gradient in scenes with a viewpoint close to the terrain. In such an area, stereo vision would enable the pilot to view the scene in three dimensions and hence judge clearance from objects and the ground.

Although this situation has subsequently been changed by the advent of CGI systems which can apply texture to faces, some recent advances in stereoscopic television systems present the opportunity of giving the pilot a true three-dimensional scene which could conceivably compensate for the lack of detail and texture gradient. If such a solution were feasible, it might be more cost effective than trying to obtain the extra detail and texture which seemed at the time to be a major problem for CGI systems.

5.11.2 Background to Stereo Study. Early in the study program a seminar was held at Concordia Univeristy in Montreal on '3-D Films and TV'. Papers and demonstrations of 3-D techniques were given by Professor Komar from the USSR, Professor Malik of Concordia University, Gerald Graham, James Butterfield, and several others, all acknowledged experts in their respective fields. The demonstrations of the Russian 3-D films were particularly outstanding and showed how powerful this media is for creating the illusion of space. It should also be noted that contrary to popular belief, a well made 3-D film does not create eye strain. The television demonstrations were not very impressive, and although the

potential of stereo to create the illusion of space was very obvious, the applications to simulator visual systems seemed remote.

A few weeks later, however, at the SID conference, a 3-D television system was demonstrated by Dr. John Roese from the Naval Undersea Center in San Diego. This system not only created the 3-D effect but did not seem to degrade the resolution of FOV of the display. It was also remarkably simple and seemed adaptable to simulators using CGI visual systems. This system will be described in detail to show how it could be used with a CGI visual.

5.11.3 Principle of Operation. All stereo systems use the technique of separating the left-and right-eye images and using some device to allow each eye to see only its respective image. John Roese's system uses the interlace feature of a normal TV display to separate the images. The odd field contains the left-eye image and the even field contains the right-eye image. The observer wears a pair of spectacles consisting of a pair of PLZT ceramic lenses that operate as an electronic shutter synchronized with the field rate, so that each eye can see only its respective field. Each PLZT lens consists of a sandwich of a front polarizer, a PLZT ceramic with an array of electrodes, and a rear polarizer. Application of a 500-volt pulse across the electrodes causes the plane of polarization of the PLZT ceramic to rotate 90°, preventing light from passing through the lens. The voltage presents no danger to the wearer because it is extremely low power.

One would expect a loss of resolution in such a system, since each eye is only seeing half the total number of scan lines; however, the brain manages to recombine the two images with little or no loss in resolution. Flicker would also appear to be a problem, but again the eye-to-brain combination reduces the flicker, although not the level of an ordinary TV display.

As can be seen in Figure 5-22, the images can be made to appear behind the screen, in which case the screen functions as a window, or in front of the screen. The eye of course is always focused on the screen, but if the object does not appear closer than halfway between the eyes and the screen, the convergence cue always predominates and no discomfort is felt. The screen of the CRT can be placed quite close to the observer when used in the window mode, with all objects behind the screen. This eliminates the need for a collimated display; however, head movement creates severe problems.

Sideways movement of the head quickly tells the observer that all objects are on the screen. When speaking at the symposium on 3-D film and TV at Concordia Univeristy, Dr. Malik stated that the interaction of the observer with the scene was the most powerful cue for depth perception.

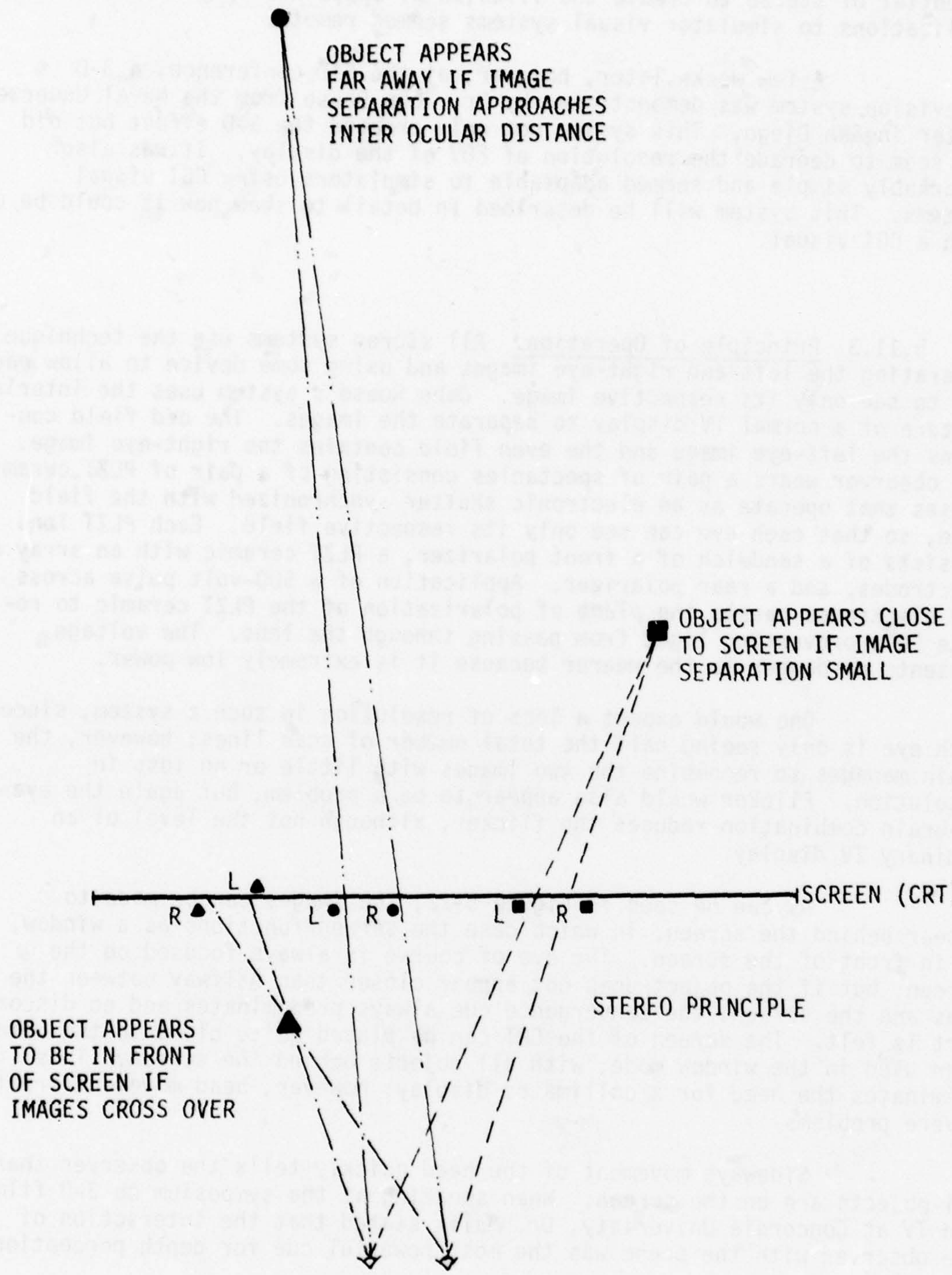


Figure 5-22. Stereo Principle

If the observer cannot interact correctly with the scene, all illusion of space is lost. If the observer's head positions can be monitored, the scene can be calculated correctly for each eye at all times. This can be done fairly easily as discussed in paragraph 5.2.3. Using this technique, a very strong interaction with the scene will occur. The CRT screen will truly be acting as a window, allowing the correct perspective scene to be seen from any angle on viewpoint. One could of course use a collimated display, in which case the scene would probably be arranged in front of the screen. Head movement would not cause as severe a problem as with a noncollimated display; however, calculating the images with respect to the head positions will preserve the illusion of space by allowing a parallax to occur between objects in the scene. It should be noted that the transmission of the spectacles is only 25%, so that when used with a mirror beamsplitter display, a brightness of only about two foot-lamberts will be achieved.

5.11.4 Stereo Applied to FWS. The PLZT spectacles work very well with a CRT, however, as discussed in sub-section 5.3 on displays, the most likely candidate for a display device is a light valve. The luminance of a standard color TV CRT decays to 10% of its peak value in about five milliseconds. The PLZT spectacles switch during the vertical retrace, and because of the rapid decay of the phosphor little energy from any part of the picture reaches the 'wrong' eye. All light valves, however, rely on long decay times to achieve high brightness levels. Typically, they decay to 15% of their peak luminance in one field scan. Therefore, the PLZT spectacles are unable to obtain sufficient isolation of the two images and each eye sees its own correct image at full intensity, together with the other image, at a much reduced but still visible intensity. Experiments were performed at the General Electric Company in Syracuse to determine the effectiveness of the PLZT spectacles with a GE light valve. Stereo pictures were obtained, but only by increasing the temperature of the oil layer to reduce the decay times to an acceptable level. This of course has the unfortunate effect of reducing the displayed brightness to an unacceptable level.

An alternative way in which a light valve may be used to obtain stereo pictures by this technique is to polarize the light from each field in orthoganal directions and use a pair of polaroid spectacles with each eyepiece similarly polarized. This can be done by placing a rotating wheel similar to that used in field-sequential color projectors in the light path. Instead of having a different color, each segment of the wheel would be polarized in the appropriate direction. Although the technique is basically quite simple, several problems would have to be solved to obtain good image separation. Tilting of the observer's head would reduce image separation, unless a similar tilt were introduced into the polarizing wheel. The use of polarized light would obviously preclude the use of pancake windows, necessitating the use of a dome.

The use of stereo TV in the FWS window display would therefore be possible, but its cost effectiveness is in doubt.

5.11.5 Further Considerations of Binocular Vision. This part of the study was undertaken solely to determine whether the stereo cue used in a CGI visual could replace the high level of detail and texture gradients found in the real world. Once it had been established in a parallel part of the overall study that CGI might provide sufficient detail by the use of textured faces, the stereo study became of secondary interest. However, the accumulation of any knowledge concerning the visual process will assist in solving the AH-64 training problem. The following observations are noted.

The evolution of binocular vision in animals is of some interest. Dr. Conrad Lorenz discusses binocular vision as being a higher level of intelligence in animals (Ref. 5-13). It has evolved mainly in animals that hunt for their prey, such as the owl, which will sit quite still until it has located the exact position of its quarry and then pounces upon it with amazing accuracy. It has also been developed in those animals that jump or swing rapidly from tree to tree. They must be able to precisely locate a branch before committing themselves to any action. Spatial perception is well developed in many animals that do not have binocular vision. These animals use the change in parallax between objects which is continually occurring when the animal itself is moving. Goldfish, for example, have a highly developed sense of parallactic vision for avoiding obstacles. The significant distinction between these two methods of spatial perception is that parallactic vision requires movement before an object is located, whereas binocular vision allows object location before movement. A goldfish may actually swim towards an obstacle before locating its position. In some animals having both parallactic and binocular vision, their use is not interchangeable, i.e., binocular vision cannot be used for collision avoidance by these animals.

An important task of the pilot in an attack helicopter flying NOE is collision avoidance, in which pilots probably use parallax as the main spatial cue. The use of binocular vision for a pilot is probably only significant when hovering close to the ground in situations offering only weak parallax cues.

Dr. Kimball's work on night vision goggles would tend to support the above statement (Ref.5-14). His studies of pilots using the AN/PVS-5 goggles show that they perform quite adequately in heavily treed terrain but have difficulty over flat grassy fields. The latter effect seems to be due to the noise and graininess of the image intensifiers masking the texture

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Ref.5-13. Lorenz, Conrad, Behind the Mirror, Methuen Press, London, 1977.

Ref.5-14. Lees, M., Kimball, K., Hoffman, M., and Stone, L., Aviation Performance During Day and Night Terrain Flight, USARL 77-3, U.S. Army ARL, Fort Rucker, 1976.

gradient cue.

An interesting experiment showing the value of parallax was performed by John Barnes in 1970 at the Human Engineering Laboratories at Aberdeen Proving Ground. By recording the eye movements of several pilots in a UH-1 helicopter performing a VFR hover in ground effect over a runway, he found that the pilots spent most of their time looking at the intersection of the edge of the runway with a prominent crack in the runway and that they aligned this point with the FM antenna of the helicopter. The parallax between this point and the FM antenna provided all the cues they needed to maintain a fixed hover. As stated in paragraph 5.2, this experiment should be repeated for the AH-64.

One last point to consider is the speed at which depth is perceived using binocular vision. While observing the stereo TV of John Roese, it was noticed that a few seconds were required to see the three-dimensionality of the scene. But what was even more amazing was that if, unknown to the observer, the scene was changed back to a two-dimensional scene, the observer continued to accept it as three-dimensional for several seconds. John Roese stated that this was a common effect, although no theoretical reason had been found to explain the phenomenon.

In conclusion, it would appear that binocular vision is of secondary use in the actual aircraft and therefore not required in the simulator. Pilots are probably aware both of this and of the importance of parallax. Three useful facts emerge from this part of the study:

(a) The design of the model, whether a CCTV or CGI system is used, should include considerable parallax cueing.

(b) Any appendage of the aircraft that is used as a sighting aid should be included in the visual simulation.

(c) The viewpoint should be calculated for the actual position of the head rather than for the nominal viewpoint.

5.12 OTHER SYSTEMS

5.12.1 Laser Scanner. The details of the Redifon laser scanner visual have been reported in a feasibility study (Ref. 5-15). The concept is an imaginative adaptation of the flying spot scanner principal and can be compared to a solid model board CCTV system with the light flowing in the

Ref. 5-15. Spooner, A., and Lobb, D., AA Final Report for the Scanned Laser Visual System Feasibility Study, American Airlines, 1976.

reverse direction. Apart from the feasibility of using such a complex piece of equipment in a simulator environment, we can find at present only one technical reason for criticizing the design.

The lighting of a terrain model board is very critical. Care must be taken to ensure an equal distribution of light on horizontal and vertical faces. In order to achieve this, the light on a particular area of model originates from many lamps at different angles and different locations on the lighting bank. A similar situation will exist in the laser scanner concept. The light path from a particular area of the model to the various sensors will vary considerably, and the resulting phase dispersions in the video signal will reduce the MTF at the higher spatial frequencies.

5.12.2 Wide Angle Visual System. The Naval Training Equipment Center (NTEC) is developing a novel visual using a 360^{0} probe. The circular image from the probe is focused on twelve linear arrays of Charge Coupled Devices (CCD) arranged in a radial pattern. The image is caused to rotate so that the linear arrays scan the entire image in 1/60 second, corresponding to one field of a TV frame. The video from each CCD is fed to a channel of a laser projector for viewing by the pilot. The integration time of the image on the CCD is about 26 microseconds instead of the normal complete field time. It would appear that the photon noise resulting from this low integration time will be the predominant noise source.

The calculation of photon noise that follows assumes the following parameters:

50^{0} vertical field of view

0.7 mm aperture for lens

30% transmission for lens

4000 foot-candles of illumination

50% reflectivity of model surface

26 usecs integration time

The estimation of photon noise requires the calculation of the average number of photons incident on a picture element at the image sensor. The number of photons per watt of radiation at 530 nanometer wavelength

$$= 2.6 \times 10^{18} \text{ per sec}$$

The number of lumens per watt in the luminance channel, i.e., between 490 nanometers and 570 nanometers is approximately 600 lumens/watt. Therefore,

The number of photons per lumen in the luminance channel

$$= 2.6 \times 10^{18}/600 \text{ per sec}$$

$$= 0.43 \times 10^{16} \text{ per sec}$$

Sensor spacing of CCD 131 is 13 μm;1024 elements subtends 50^{0} (vertical field of view). Therefore,

$$\text{focal length} = \frac{1042 \times 13 \times 10^{-6}}{2 \tan 25} \text{ in.}$$

$$= 14.3 \text{ mm}$$

Therefore

$$\text{F. No.} = \frac{14.3}{0.7} = 20.4$$

Image illumination for 2000 foot-lamberts of object brightness

$$= \frac{2000 \times 0.3}{4 \times (20.4)^2}$$

$$= 0.36 \text{ foot-candle}$$

Picture element size

$$= 8\mu \times 13\mu$$

Picture element area

$$= 8 \times 13 \times 10^{-17} \times 10.76 \text{ sq. ft.}$$

$$= 1.12 \times 10^{-9} \text{ sq. ft.}$$

Number of photons per picture element per second

$$= 0.43 \times 10^{16} \times 0.36 \times 1.12 \times 10^{-9}$$

$$= 0.173 \times 10^{7}$$

Number of photons per picture element per field, assuming 26 μsec integration time

$$= 0.173 \times 10^{7} \times 26 \times 10^{-6}$$

$$= 45$$

If we assume a 100% quantum efficiency in the sensor, the signal-to-noise ratio will be determined by the statistical fluctuations in the number of photons, which is given by the square root of the average number of photon. That is, signal-to-noise ratio

$$= \sqrt{45}$$

$$= 6.7$$

This would have to be increased considerably before an acceptable picture was obtained

5.13 PREFERRED APPROACH

5.13.1 CGI or Model Board. The original CAE proposal for this study program stated quite clearly that we did not believe CGI was adequate for a NOE environment and that a solid model board approach was the only feasible alternative. During the course of the study, our views have changed somewhat at times even tending to the opposite point of view. Our present views are by no means unanimous and can be categorized as follows:

(a) Both systems can offer adequate visual cues for both pilot and copilot, with CGI being more cost effective in the long run.

(b) Both systems can offer adequate visual cues for pilot and copilot, but the added realism of a solid model would allow more effective training.

(c) The CGI approach is unproven in NOE flying and presents an unacceptable risk for a production contract.

The latter view may be changed by a study that GE is presently conducting for ARI at Fort Rucker. GE has been given a film used for navigational training, consisting of a NOE flight, and is attempting to generate a similar film using CGI techniques. If a navigator can trace the correct route on a map while watching the CGI version, it will at least prove that navigation can be done on a CGI system. It is reasoned at ARI that since navigation is the most difficult task in NOE flight, the success of the study would also prove that a pilot could fly NOE in a CGI visual. This argument is open to question since different perceptual processes are used in the two tasks; however, the study will provide valuable data and will at least provide an estimate of the number of edges required per square kilometer.

The rider to the first view, i.e., that CGI systems are more cost effective, is based on several premises:

(a) Model boards consume more energy.

This is certainly true, even though the CGI systems being considered are by no means small consumers of energy. Approximate figures, neglecting air conditioning requirements, are 400 kilowatts for a proposed two model board system and 130 kilowatts for the 3 TEPIGEN system, a factor of three. It should be noted, however, that the cost of this power is small compared to the total cost of servicing a simulator, and the energy consumed is considerably less than that required by an AH-64.

(b) Model board systems require more maintenance.

From our own experience and from discussions with the maintenance engineers at the Boeing simulator center in Seattle, which has a GE CGI system, the difference in manpower would be insignificant. The difference in cost may be appreciable, but again only a small part of the overall simulator cost.

(c) Model board systems are more costly to purchase.

Even when building costs are included, this would appear to be untrue.

(d) CGI systems can reaily change data bases and therefore offer more training.

The first part of this premise is true, but the second part is open to question. For one thing, the purchase of six simulators will allow six different types of terrain to be modelled, even if a model board is used. It should be firmly established that the ability to change model data bases at a given simulator location increases the training value of that particular simulator before assuming this as a valid criterion. It certainly offers some interesting training possibilities. Colonel Sims raised the question of two AH-64 crews training together and, looking to the future, suggested that an Advanced Scout Helicopter (ASH) crew should be included in the team. This could be achieved by using identical data bases and a communication link between the simulators, even if the simulators were at different bases several thousand miles apart.

(e) CGI is a new technology and therefore more cost effective.

This statement is somewhat reminiscent of the statements made by computer manufacturers many years ago that computers would free mankind from the drudgery of work. It is a new technology, however, and progress being what it is one can expect significant advances in the future. Indeed, the advent of texture will probably have the same effect on CGI systems as the advent of jet engines on air travel. The premise does, however, assume that there will be no future progress in model board systems. The

discovery of a photocathode with a quantum efficiency of 60% rather than the present 6% would, for example, reduce model board power requirements to below those of present CGI systems. The wavelength of light determines the size of model board systems, which are not likely to be reduced, whereas the number of cabinets of parallel processors required in CGI systems will surely diminish. This is certainly a benefit of a new technology.

(f) CGI systems offer playing areas larger than model board visuals.

This is undoubtedly true. The suggested model board approach will have a maximum playing area of only 3.5 by 11.6 km, whereas a 20 x 40 km playing area is possible using the CGI approach. However, the use of CGI for the TADS enables the tactical area in the model board approach (i.e., that area in which threats can be engaged) to be extended to 11.5 x 19.6 km. This is probably adequate, considering that the prime use of the simulator will be to practice shooting and self-defense rather than flying and navigation. It should also be realized that the creation of a highly detailed 20 x 40 km area will be a considerable task in itself. GE has estimated that 100,000 edges per square kilometer will be required, i.e., 80 million edges for the complete area.

The second viewpoint at the beginning of this section suggested that realism might add to the training value of model board systems. And here perhaps lies the crux of the whole argument.

CGI systems have been used quite successfully in fixed-wing simulators by USAF helicopter pilots; however, flying at NOE altitudes is much closer to nature than is the case with airforce pilots flying high performance fighters. The name Air Cavalry describes the function of helicopter pilots very accurately. It is of course impossible to make a visual system having the detail of the real world, but the brain seems to be able to accept present high quality visual systems as being very close to the real world. Dr. Jim Bynum suggested that the Army could train its pilots and gunners to accept the cartoonish nature of CGI and treat the simulator as a training device. If the Army can guarantee that a visual system offering scenes such as those discussed in paragraph 5.10 can be accepted by pilots and gunners to the extent that no further realism is necessary, the choice of CGI or model board can be made on purely objective grounds. Accordingly, we describe two approaches, believing that both may be adequate for training the AH-64 missions.

The extra realism provided by the model board approach, together with the fact that the restricted playing area does not seem to impose a severe restriction on a mission in which 'shooting' is the primary training task, leads us to prefer the model board approach.

5.13.2 Model Board Approach for the AH-64 FWS

5.13.2.1 General. The purpose of this section is to describe the preferred approach for implementing a model board/CCTV visual on the AH-64 FWS.

Many compromises are made when designing visual systems; however, the attributes of the model board/CCTV approach which make it preferable to a CGI system should not be compromised. The three reasons that might make a model board/CCTV system preferable are:

(a) The lack of realism in a CGI visual could significantly detract from the training value of the device.

(b) The CGI system may not have sufficient foreground detail and texture to enable the pilot to fly NOE.

(c) Forested areas such as Fort Bragg may be required, and it is doubtful that the CGI could supply the level of detail.

The most significant attribute of the model that allows it to cope successfully with these three problems is the tremendous amount of detail model makers can put into each square inch of the model. The two parameters that control this attribute, apart from the model maker's skill, are cost and scale. Making a model that will allow NOE flight and tactical maneuvers over its entire area will be costly, especially if large forested areas are required. Scale factors have been discussed in paragraph 5.9.2. It would appear that 500:1 is the smallest scale that will allow sufficient depths of focus when flying at altitudes of only a few feet above the ground or above the tree tops. Any compromises in this area will give poor focus in some part of the picture, resulting in confusing depth cues and general degradation of the image. Since the aircraft will be flying very low to the ground most of the time, it is necessary to have high image quality in this mode.

Once a model of 500:1 has been established, the playing area is limited to about 3.5 by 11.6 km for a 24-by 76-foot model. The tactical area, i.e., that area in which targets can be engaged, can be extended, however, by the use of mirrors, special effects, and the TADS to 11.5 by 19.6 km. This figure is arrived at by adding the range of the TADS and the Hellfire, i.e., 4 km to each side of the model. A typical model is shown in Figure 5-23. The entire area can be used for tactical missions with targets, missile tracks, and explosions appearing anywhere, but only the central area can be used for flying. Models of enemy threats could be placed along the planned mission route before an exercise, or unseen threats could be placed anywhere during the mission by the instructor.

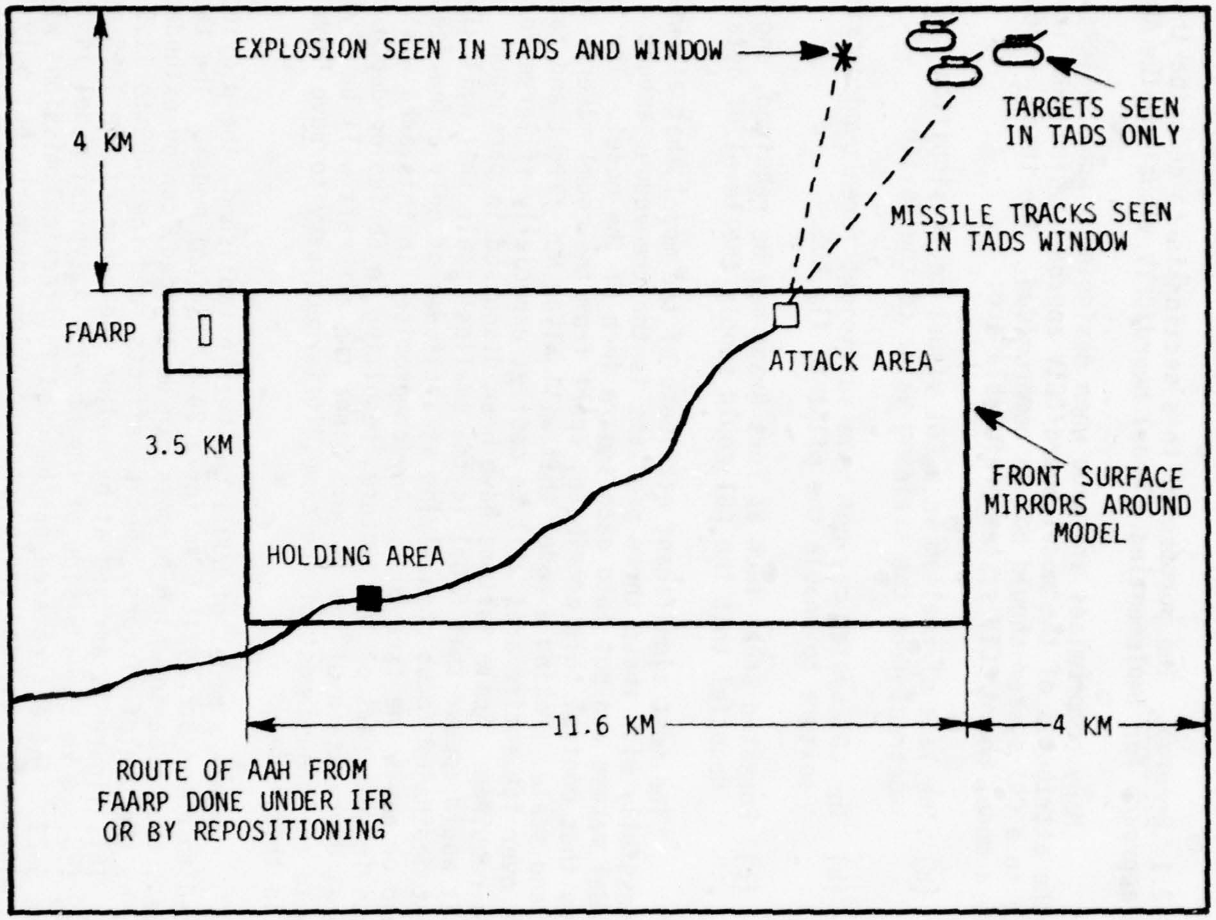


Figure 5-23 Use of Mirrors, Special Effects and TADS to Extend Tactical Area

The unseen threats would be able to fire various weapons, with the flashes appearing to come from the threat positions. The AH-64 could respond by firing at the flashes. Careful planning of the model will allow many missions to be flown without using the same route, and many attack areas, target areas, and holding areas can be designated in different areas of the model for each mission. As long as missions are planned that avoid the probe looking directly at a mirror at close range, the probe reflection will not be obvious.

For a model similar to the country around Fort Bragg or Fort Rucker, we could assume the highest contour would be 200 feet above the lowest point and that NOE flight would not go above 250 feet above the lowest contour. This will allow six-inch mirrors to be placed around the model with a 2-foot backdrop above to alleviate the sky problem. During NOE missions a 250-foot cloud base could be assumed. Training requiring altitudes up to 1000 feet could still be carried out, but the edge of the model would not be the true horizon. Reduced visibility at the higher altitudes would reduce this problem and would also prevent the trainee from becoming too familiar with the model. Mountainous models could also be made, and it is probably desirable that models at each installation have a different type of terrain.

The approach has its limitations, but if the playing area is insufficient, it would be advisable to go to a CGI system rather than to increase the scale factor. However, we feel that this system, combined with a CGI TADS, will provide a great deal of tactical training.

5.13.2.2 TADS Simulations (Day Only). As explained in paragraph 5-6, the high magnifications cannot be obtained by using a 'dual probe' approach. CGI offers an acceptable alternative solution. The resolving power of the FLIR and TV can be simulated quite accurately. Any defects caused by diffaction, lag, etc., can be simulated once the design of the TADS is known. The target detection capability of the low-power direct optics can best be simulated by exaggerating the size and color of the target. The high-power direct optics will require the insetting technique described in paragraph 5-6 to obtain the desired resolving power. A resolving power of about four seconds of arc could quite readily be obtained; however, this is probably better than the TADS itself, and it might be preferable to have a lower resolving power which would enable larger arrays of tanks to be displayed. The data base for the TADS will have to correspond very accurately to the model data base.

5.13.2.3 FLIR Simulation. The FLIR for both copilot/gunner and pilot is best simulated with CGI rather than processed video (see paragraph 5.4.2). There would be no cost saving in using processed video since the TADS requires a CGI. The diurnal and nocturnal cycles of the FLIR image can probably be simulated quite well in a CGI system along with target signatures.

5.13.2.4 Targets. As explained in paragraph 5.1, distant tanks will not appear in window displays apart from debris and dust thrown up by their tracks, which will be simulated using special effects. CGI models of tanks, etc., would be seen in the TADS. Even enemy helicopters could be simulated in this way.

Enemy threats could be placed anywhere on the model and engaged at short range. A moving truck convoy could be used on one panel of the model for intermediate range attacks using rockets and cannons. Both these types of targets could also be seen using the TADS or PNVS.

5.13.2.5 Weapons. Weapon effects will be simulated in the window display by the use of special effects (refer to paragraph 5.7.10) and in the TADS and PNVS displays by direct insertion into the CGI data base.

5.13.2.6 Sky. The best approach for generating sky has not been ascertained at present. The keying solution (refer to paragraph 5.7.10.4), presents several problems and so does the white backdrop approach. A combined approach seems the most promising, allowing keying to take place above the backdrop but below the lighting bank as shown in Figure 5-24. An interesting observation made during integration and demonstration of our CH-47C simulator, which has a very mountainous model, is the pilot's acceptance of a model with no sky. The sky adds to the picture aesthetically, but the lack of it has no effect on pilot performance. This may not be true on a predominantly flat model.

5.13.2.7 Probe. A simple non-tilt probe with three separate outputs, each having a symmetrical mapping function about its own axis, is the recommended probe type. Farrand has made significant advances in tilt probes, and the difference in MTF between tilt and non-tilt probes is minimal and approaches the diffraction limit for both types. The tilt probes, however, require 50% more light on the model, are considerably heavier, and considerably more complex. Furthermore, in NOE missions, the tilt feature cannot be used all the time as explained in paragraph 5.8. Even if a

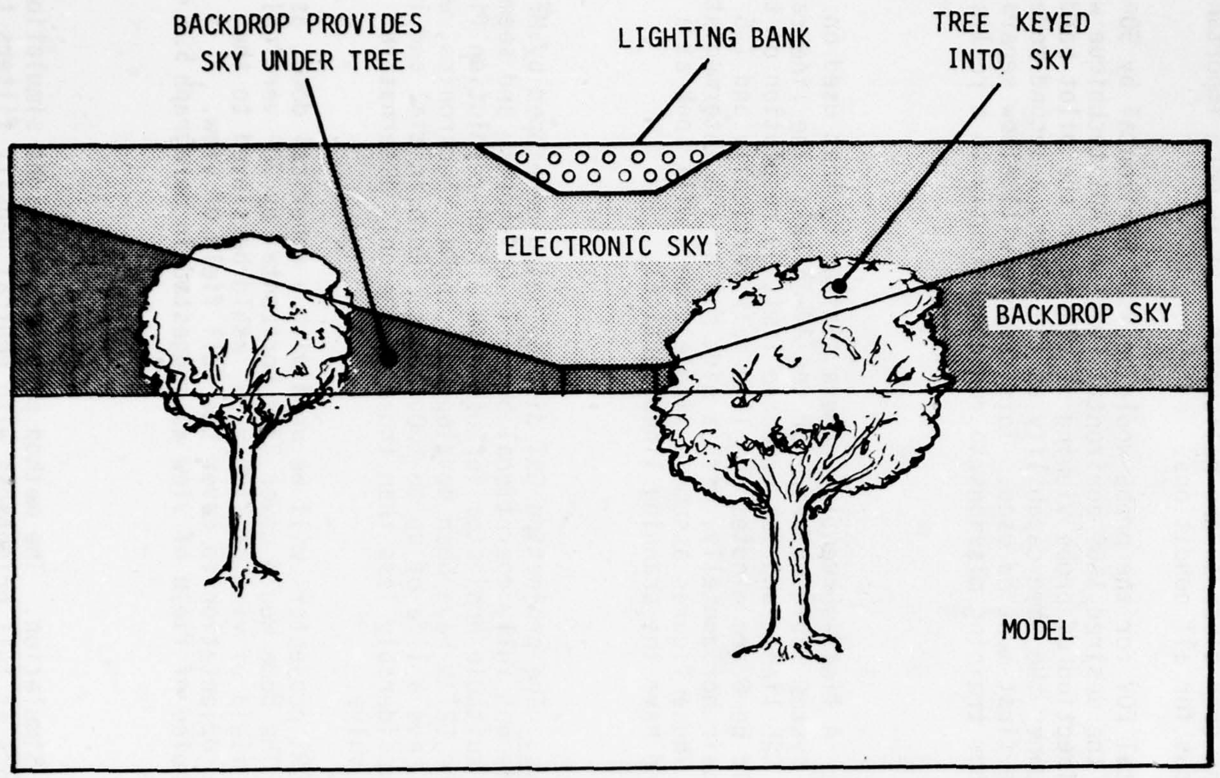


Figure 5-24 Diagram Showing How a Combination of a Backdrop and Keying Can Provide Sky

program could be derived to enable the tilt to be used near the ground as a function of the proximity of vertical objects, the increase in ground focus under certain conditions would have a dubious training value. The Iranian CH-47C simulator demonstrated that pilots quickly get used to an out-of-focus condition of the ground very close to the helicopter. It is more important to have consistent focus for all conditions.

The total FOV for the probe would be 110° horizontal by 50° vertical. To achieve the desired 180° horizontal FOV, and AOI technique will be used so that the direction of probe viewing is slaved to the pilot head. To give the copilot/gunner the same capability as the pilot, a second model board identical to the first must be used. This feature will allow separate pilot and copilot/gunner training missions to run concurrently in a realistic environment.

5.13.2.8 Camera. A field-sequential camera similar to that used on the Iranian CH-47C visual system would be used for the AH-64 FWS. The line rate would be increased to 925 lines, and the expected limiting resolution of the whole video chain would be 6 arc minutes per line pair vertically and 7.5 arc minutes per line pair horizontally, with a high MTF at the intermediate spatial frequencies. These figures assume a single camera will look at a 50-by 38-degree FOV and have the scanning lines vertical.

5.13.2.9 Displays. The projection CRT display being developed by Mr. Al Cosentino at Grumman is not fully operational but will be shortly and seems likely to be the most suitable projector for use with a high-resolution field-sequential camera. The CRT's have been developed by Thomas Electronics, which claims that they will have a life of up to 2000 hours. Both initial and life cycle costs will be considerably less than those of the only alternative projector, a GE light valve.

Three CRT projectors will be used with a spherical dome, as shown in Figure 5-9. The dome would cover 220° horizontal by 70° vertical, and the instantaneous field of view of 110° x 50° would be slaved to the pilot's/copilot's head orientation to cover the full field of view. A study verifying the choice of field of view as suggested in paragraph 5.2.4 would still be useful.

5.13.2.10 Night Simulation. The method proposed for night simulation is to run the projectors at full brightness with neutral density filters to give scene illuminations of between 10^{-5} and 10^{-3} foot-candles. The actual level could be set by the instructor and would cover the awkward area where both retinal rods and cones are working, as well as the true night

conditions where only the rods are working. The resolution of the display would match the resolution of the eye at these levels, resulting in very realistic images.

Any cultural lights, gun flashes, or other bright point sources would be shown on the helmet-mounted display no matter what other imagery was present. Bright lights on the window display will be dimmed along with the rest of the scene, but the brain will merge the window display and helmet display to obtain a single scene. The FOV over which the lights can be displayed will only be 30 x 40 degrees; the field or regard, however, would be limited only by the windows of the aircraft.

The FLIR imagery will be generated by CGI in the same manner as for TADS. It will of course have to correspond to the model, but for very dark nights when nothing can be seen with the unaided eye, the helicopter could be flown beyond the bounds of the normal playing area. The use of night vision goggles such as the AN/PVS-5 will be possible, but the effect of the bright lights will not be correct because of the low display brightness. If cultural lights are required, they would have to be included on the model or provided by special effects.

5.13.2.11 Scout Helicopter. A model helicopter would be viewed with another camera and keyed into the main video to represent a scout helicopter. The data base and algorithms for computing line of sight to targets will enable the helicopter to be occulted as it goes behind a tree. Colonel Martin at Fort Knox and Colonel Sims at Fort Monroe stressed the need to actually see the scout helicopter, and Colonel Sims thought the second AH-64 should also be shown. Provided only one helicopter could be seen at a time, a scout, AH-64, A10, or even a Hind gunship could be provided at a reasonable cost. The ranging could be done with a 16:1 zoom lens and the helicopter mounted on gimbals to attain the three degrees of rotation. Lateral movement could be accomplished electronically. The helicopter would also be modelled in the CGI for the TADS and PVNS. Operation of the other aircraft could be preprogrammed or controlled by the instructor.

5.13.3 Proposed CGI System. The following paragraphs describe the preferred CGI approach. TERPIGEN is an acronym for Television Picture Generator and is manufactured by Marconi Radar Systems of Leicester, England. It is the only CGI system offering realistic texture and in our opinion the only system that could offer adequate cues for the NOE flight over a large area. The first system will not be fully operational until October 1978, which raises several doubts as to the potential of the final system. However, much information has been disseminated by the simulation community, and the Marconi engineers seem to appreciate the problems that can degrade a CGI system. Certainly the quantization of the picture due to the digital nature of the computation, the degradation caused by the raster

structure of the display, and the importance of animating the picture at the field rate have been adequately considered.

The ability of Marconi to manufacture the required number of systems within the schedule of the AH-64 program should not be questioned. It is an established firm with a high reputation and delivers about £70 million of electronic equipment annually.

5.13.3.1 <u>Summary of the Proposed System</u>. Each of the three TEPIGEN systems in the proposal have the characteristics listed below:

Face Capacity	3000
Edge Capacity*	5250
Light Capacity	10000
Animation Rate	60 Hz
Number of Raster Lines	875
Number of Change Points per Raster Line	210
Number of Color Hues Available	$>2 \times 10^6$
Color Hues in O/P Scenes	Equal to the number of faces/ lights
Element Resolution ($50^o \times 38^o$ FOV)	8 arc minutes/line pair
Vernier Resolution with Edge Smoothing	1 arc minute
Number of Independent Data Channels	4 System capacity shared between channels to provide an Area of Interest (AOI)
Atmospheric Effects	Aerial perspective Variable visibility Variable luminance (e.g., daylight/night) Variable Transparency for smoke and clouds
Texture	Apparent edge capacity improvement factor: 10 to 100 Applicable to any face
Number of Textures	2^{19}

Special Effects	Attenuation of scene intensity by rotor blade
Maximum Observer Turning Rate (for 50^{o} x 38^{o} FOV with Maximum Face Capacity)	40^{o} per sec. Above this rate the background scenery is simplified to allow turning rates of up to 100^{o} per sec.
Data Base Storage+	400,000 faces 700,000 edges

* A system using the full capacity of edges excludes the use of lights. A light/edge mix may be employed on the basis of a 2:1 light: edge substitution.

\+ Can be expanded with additional mass storage

5.13.3.2 General Description of the Visual System. A block diagram of the visual system is shown in Figure 5-25. Three projectors will be used for each cockpit display, with a spherical screen covering about 200^{o} horizontally and 70^{o} vertically. The instantaneous field of view will be 110^{o} horizontally by 50^{o} vertically and will be slaved to the pilot's or co-pilot's head in azimuth and pitch.

The pilot's scene will be generated by TEPIGEN 1 and half of TEPIGEN 2. Each of the four outputs of each TEPIGEN is independent, and the number of faces allocated to each channel, and therefore to each display can be varied on-line. If the pilot's helmet display is switched on, SW1 will be in the position shown and TEPIGEN 2A will supply whichever mode of video is selected. The faces from TEPIGEN 1 will be evenly distributed among the three projectors for the window display.

The copilot's scene will be generated by TEPIGEN 3 and the other half of TEPIGEN 2. The allocation of faces is a little more complicated for the copilot, since the TADS head-up and head-down displays must be considered as well as his helmet display. If no internal displays are switched on, SW2 will be in the opposite position, as shown in figure 5-25, and the total number of faces will be evenly distributed among the three window projectors. If any FLIR or TV mode has been selected, faces from TEPIGEN 3 will be re-allocated to the copilot panel display. The number of faces allocated to this display will vary according to the copilot's head position. If he is looking directly at the display, several hundred faces will be used, whereas if he is gazing out of the window, less than one hundred faces will be sufficient. This display is primarily used for status information so that high quality imagery is not necessary. When the copilot places his head in the boot, pressure against the eyepiece activates a switch that causes the CRT to be imaged through the eyepiece. This switch will cause most of the face capacity to be allocated to the boot display.

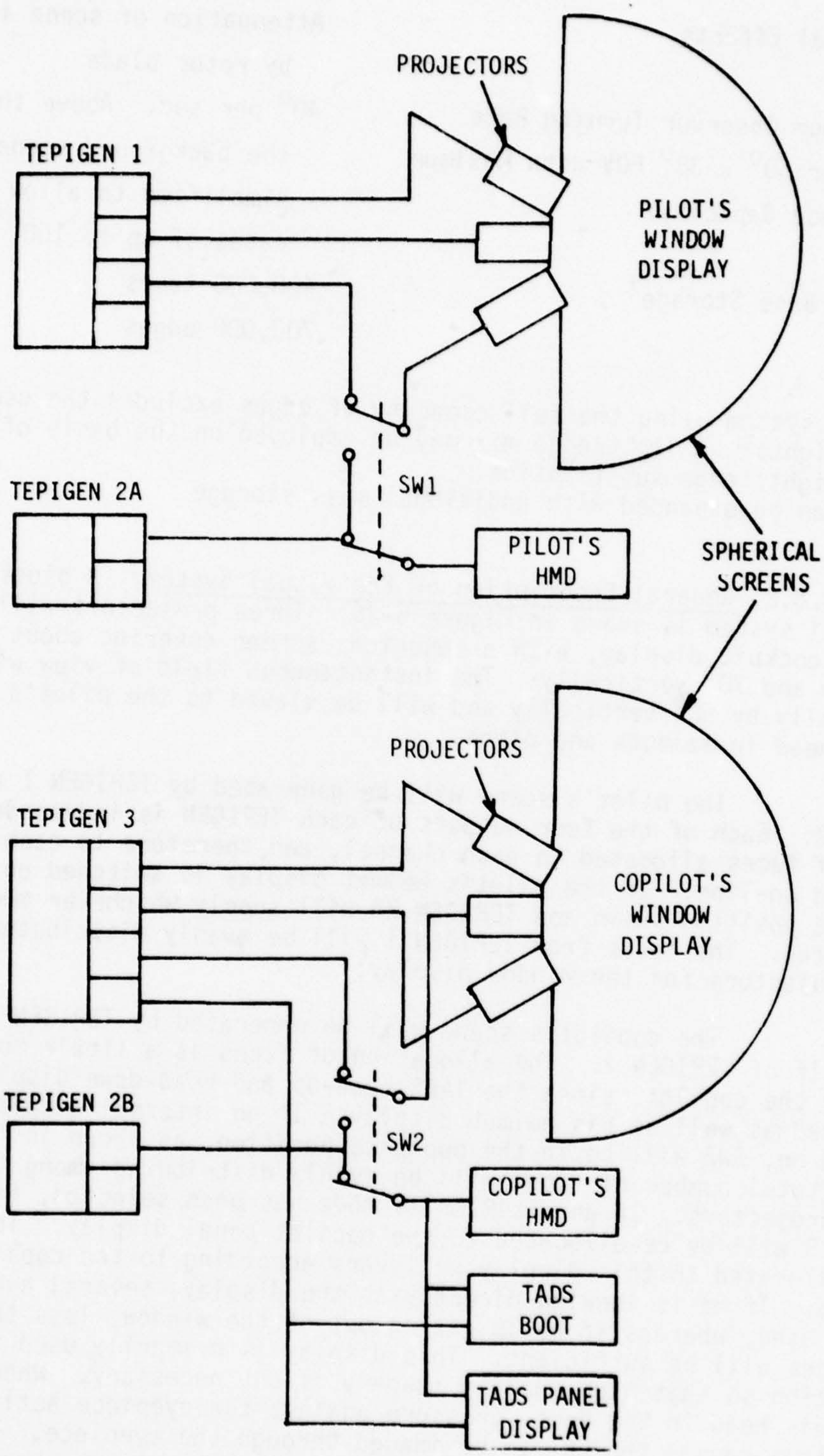


Figure 5-25 Block Diagram of CGI System

If the direct view mode is selected, SW2 will direct the video from TEPIGEN 2B to the boot. These faces will be used solely for the insertion of high resolution targets as discussed in the TADS sections. In this manner, a highly detailed view will be available in any mode of the TADS when it is used in the head-down position while maintaining a low level of detail in the window display. This will enable a realistic transition from head-down to head-up position.

Operation of the helmet display will be similar to the pilot's helmet display. TEPIGEN 2B will provide the imagery for the helmet display while TEPIGEN 3 will provide the scene for the window display. If imagery is required on the head-up TADS display while the helmet display is in use, faces will be re-allocated from TEPIGEN 3. The night vision devices will use the same data base as the visual scene, but FLIR parameters will be substituted for the visual parameters. Similarly, the TV data may include certain parameters relevant to the near infrared response of the sensor.

The simulator computer will provide the following information to the appropriate TEPIGEN:

- Pilot's head position
- CPG's head position
- PNVS orientation
- TADS orientation
- Missile image seeker orientation (if used)
- TADS sensor selection and magnification
- Weapons trajectory and impact points
- Velocity of rotor blades
- Instructor's control data for target types and positions, preplanned target tracks, visibility, and light level.
- Any other special effects

The TEPIGEN system determines the position and orientation of all of the models from which the scenes are to be composed, mathematically projects the models onto a plane, and scans the resulting projection to generate the required video signals. The appropriate video signal is applied to a display device to generate the desired image.

The TEPIGEN systems also provide the host computer with the position of those targets moving along preplanned tracks and also the altitude of other ground targets. For simplicity, this output is not shown in Figure 5-25.

5.13.3.3 The TEPIGEN System. The scenario processor, shown in Figure 5-26, determines which models stored in the backing store are needed to be processed by the picture, texture, and display processors in order to generate the appropriate video signals. The data for these models is then transferred from backing store into the picture and texture processors. In addition, the scenario processor computes the altitude and orientation of ground based targets. Environmental inputs from the simulator are monitored by the scenario processor, and the appropriate data is generated and passed on to the picture processors. It is proposed to employ two Digital Equipment Corporation RK06 disks in the backing store, with the model data shared between them. Assuming average latency and seek times and assuming an organization of data that minimizes the lengthy multi-track searches and maximizes the number of quicker track-to-track searches, the time required to extract the full capacity of face data from the disks was estimated; assuming that this full capacity corresponds to a 40^{o} field of view, the corresponding rate of turn was determined. The results are shown in Table 5-7.

TABLE 5-7. ESTIMATES OF TIMES TO EXTRACT DATA FROM DISKS

Face Capacity	Time Required to Extract n Faces (secs)	Rate of Turn (^{o} per sec)
1000	0.40	100
2000	0.83	48
3000	0.95	42
4000	1.22	33
5000	1.35	30

Further study is required in this area to determine whether a faster disc is required.

Once the observer or sensor turns at a faster rate than those given in Table 5-7, the data extraction saturates. The following method is used to alleviate this problem.

A selected number of models surrounding the observer are held in store. All trees and bushes, for example, within a 100-meter range of the observer may be described by 1000 faces requiring approximately 30 K words of store. This data can be transferred to the picture processors and the video signal generated within 100 msec. The remaining scenery would consist of greatly simplified models having less than 1/10 of the faces of the detailed models they are to represent and having the average color of

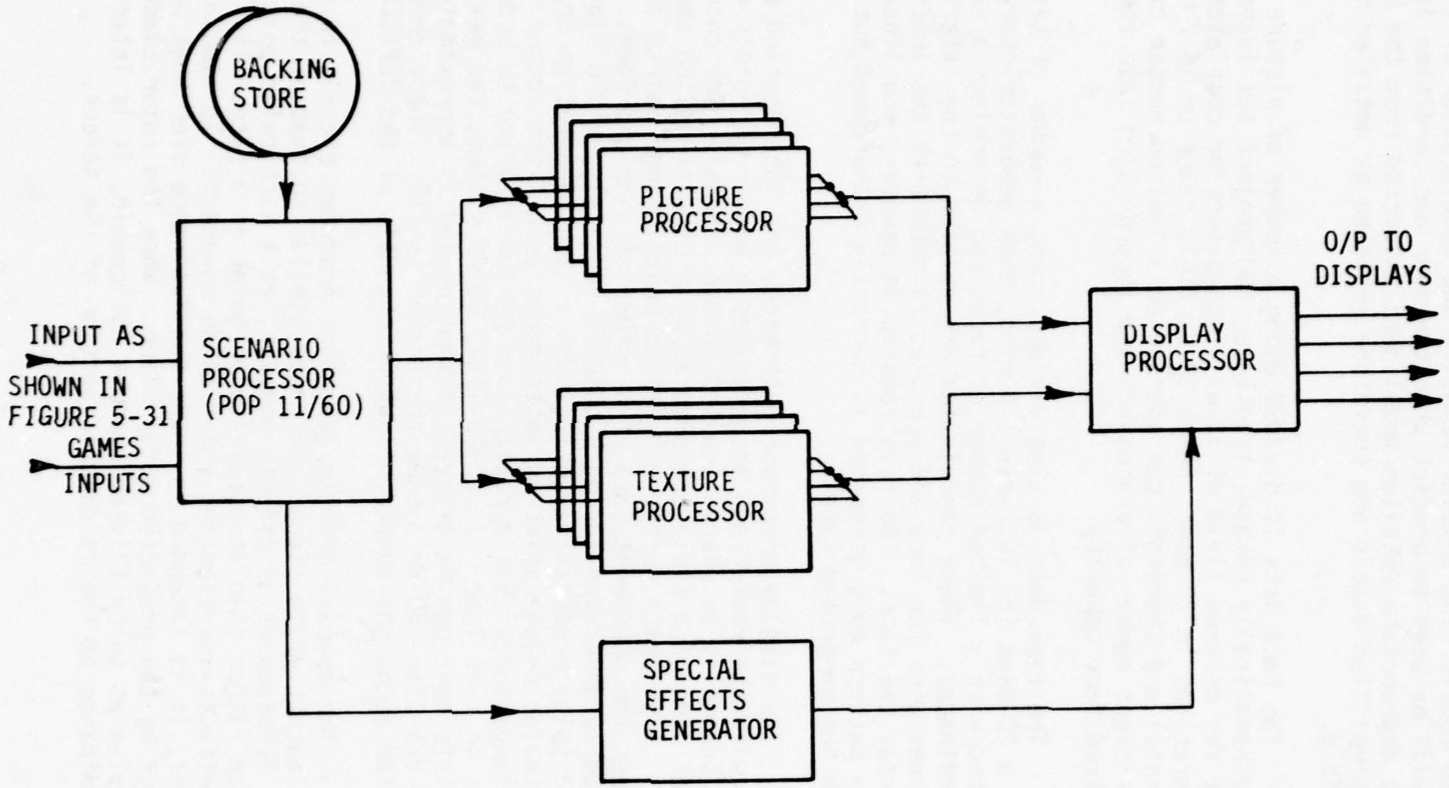


Figure 5- 26 TEPIGEN System Block Diagram

those detailed models. The angular velocity and acceleration of the observer (or sensor) will be used to predict when the overload condition is likely to cease and the appropriate detailed model data extracted from the backing store. The simplified models are therefore replaced by detailed models as soon as possible.

The face data is divided among a number of picture processors which mathematically rotate, translate, and project the faces and cull those outside the desired field of view. Each processor completes its sequence of operations in 20 msec (for a 50-Hz field rate) or 16.7 msec (for a 60-Hz field rate) and therefore can operate on a limited number of faces only. A sufficient number of processors are incorporated into the system to meet the desired face capacity.

The face data is also divided among a number of texture generators. In a 20-msec (or 16.7-msec) period, each generator operates on the data associated with a limited number of faces and determines a set of tracking coordinates. These coordinates are related to the intersection of the raster lines with the face and are used to determine the intensity of the color across the face. The relationship is however, non-linear, as that the intensity pattern thus generated is correctly transformed but remains coherent with the projected face.

The display processor determines the intersection of the projected faces with the raster and so generates a number of points where the color of the screen is to change (called change points). The change points on each raster line of a field are ordered by a circuit called the change point sorter. A priority sorter determines which change points are valid. This determines the uppermost face of a number of overlaid faces. Edge smoothing data is generated for each channel and analog video signals produced. The display processor also includes a light generation channel in which a particular change point is interpreted as a light rather than an edge. The change sorter has a raster line period in which to order the change points on that line. In a 625-line, 50-Hz system, the maximum number of change points that can be ordered in that period is approximately 350, whereas in a 875-line, 60-Hz system the number is 210. These change points are distributed among the number of output channels of the TEPIGEN system.

The special effects generator produces signals to amplitude-modulate the output video signals in a way similar to that of the texture generators. It produces an effect, however, at a particular point on the viewing screen rather than at a particular point on a face. Its function is to generate effects representing rotor blade movement. To simulate rotor blade movement, it is intended to lower the luminance over that portion of the screen cut by the projected rotor blade. When the rotor blade speed falls to a value at which flicker becomes noticeable, it is intended to pulse the luminance of the calculated portion of the screen.

5.13.3.4 TEPIGEN System Capacity. There are three processes that limit the edge capacity of the TEPIGEN System. The first concerns the gathering of data from the picture processors by the display processor. For a 50-Hz system, 4000 valid edges can be processed by the display processor during the 20-msec period. Allowing for edges outside the field of view and for edges belonging to reversed faces, the picture processors must be capable of processing approximately 8700 edges, i.e., 5000 faces. Table 5-8 summarizes limitations for a 50-Hz and 60-Hz system.

TABLE 5-8. LIMITATIONS DUE TO DISPLAY PROCESSOR

Frame Rate	Line Standard	Processing Time	No. of Valid Edges	Edge Capacity	Face Capacity
50 Hz	625	20 msec	4000	8700	5000
60 Hz	875	16.7 msec	3300	6700	4200

The second concerns the transfer of data from the backing store to the picture processors. This problem has already been discussed (see Table 5-7).

The final process is that of ordering the change points along a raster line. The number of change points on a raster line produced by the system is a function of the number of faces (or edges) being processed and their distribution in the scene. An early prototype TEPIGEN system has a limit of 32 change points per raster line. For reasonably uniformly distributed faces throughout the scene, this limit tends to be exceeded when the number of faces being processed exceeds approximately 450. From this experience, it is considered unnecessary to provide a system whose face capacity outweighs its change point per raster line capacity. Using the change point per raster line limits quoted earlier, the parameters for the H2 system are given in Table 5-9.

TABLE 5-9. LIMITATIONS DUE TO NO. OF CHANGE POINTS PER RASTER LINE

Frame Rate	Line Standard	No. of Change Pts per Raster Line	Edge Capacity	Face Capacity
50	625	350	8700	5000
60	875	210	5250	3000

It is therefore recommended that each of the three TEPIGEN systems have a capacity of 3000 faces for a 60-Hz, 875-line video output. The use of texture enhances the picture complexity by an estimated 10 to 100 times, i.e., the effective edge capacity of a 5250-edge TEPIGEN system lines between 50,000 and 500,000 edges.

Since the change points generated may be interpreted as lights or as belonging to edges, there is a direct trade-off between the edge and light capacities of the TEPIGEN system. In general, one edge is equivalent to two lights. The lights may be of the color and are variable in size. They may also be defined as omnidirectional or undirectional.

5.13.3.5 Targets. As explained in paragraph 5.1, distant tanks will not appear in window displays apart from debris and dust thrown up by their tracks. The actual tank will appear in the TADS. Enemy helicopters can also be simulated in this manner. Enemy threats can be placed anywhere in the data base and engaged at short range. A moving truck convoy could also be placed in an appropriate part of the data base for intermediate range attack with rocket and cannon. Both of these types of targets will also be seen in the TADS and PNVS.

5.13.3.6 Weapons. Weapon effects will be inserted directly into the data base. Weapon trajectories will be calculated in the main simulator computer and fed to the CGI computer.

5.13.3.7 Displays. A high-resolution GE light valve, Type PJ5800, seems to be the most suitable projector at this time. If the Hughes light valve proves to be superior during the course of the project, it could be substituted with only minimal redesign effort. Three projectors will be used on each cockpit with a 12-foot radius spherical screen covering 220^{o} horizontal by 70^{o} vertical as shown in Figure 5-25. The projectors will provide an instantaneous field of view of 110^{o} horizontal by 50^{o} vertical and will be slaved to the pilot's/copilot's head orientations to cover the field of regard. The image perspective will be calculated for the actual head positions of the pilot/copilot to avoid incorrect parallax cues with head movement. It is still recommended that a study of the required field of view be carried out, using an eye mark recorder as suggested in paragraph 5.2.

5.13.3.8 Night Simulation. The method proposed for night simulation is to run the projectors at full brightness with neutral density filters to give scene illuminations of between 10^{-5} to 10^{-2} foot candles. The actual levels could be set by the instructor and would cover the awkward area where both retinal rods and cones are working, as well as the true night conditions where only the rods are working. The resolution of the display would match the resolution of the eye at these levels, resulting in very realistic images.

Any cultural lights, gun flashes or other bright point sources would be shown on the helmet-mounted display, no matter what other imagery was present. Bright lights on the window display will be dimmed along with the rest of the scene, but the brain will merge the window dis-

play and helmet display to obtain a single scene. The FOV over which the lights can be displayed will only be 30 x 40 degrees; the field of regard, however, would be limited only by the windows of the aircraft.

The FLIR imagery will be generated by CGI as described in paragraph 5.4.2. The use of night vision goggles such as the AN/PVS-5 will also be possible, but the effect of the bright lights will not be correct because of the low display brightness.

5.13.3.9 Friendly Helicopters. Either scout or other AH-64 helicopters can be included in the data base for the out-of-window display, provided they are within 1000 feet of the simulated AH-64. At ranges greater than this, a small dot could be provided. These would move under either preprogrammed or instructor control.

SECTION 6

MOTION CUEING SYSTEMS

6.1 INTRODUCTION

The objectives of a flight simulator motion cueing system are to reproduce as much as possible the sensations of movement experienced by the crewmembers in an actual aircraft. These sensations are felt by the human vestibular and kinesthetic sensors (Refs. 6-1 and 6-2). The vestibular system consists primarily of the semicircular canals and otoliths located behind the ear, which sense angular and translational movement, respectively. Other kinesthetic sensors are those, for instance, which sense skin pressure, which can result from accelerations imparted to the body through seat contact points.

Motion cueing systems have traditionally consisted of a computer-controlled moving cockpit system operated by electrohydraulic actuators. In recent years additional seat-controlled cueing systems have been introduced which impart movement and pressure cues through the seat pan and seat cushions (Refs. 6-1 and 6-3).

Traditional flight simulator motion systems cannot reproduce aircraft accelerations completely because of physical limitations of travel. However, it has been shown that such motion systems can improve pilot performance (Ref. 6-4).

The g-seat and seat motion systems have been introduced to provide additional cue effects, and the application of these devices to the AH-64 simulator is discussed below.

The selection of the motion cueing system for the AH-64 simulation will be based upon:

(a) The training maneuvers required, particularly the magnitude of accelerations and frequency.

(b) The reproduction of vibration and buffet.

(c) The problem of motion sickness, in view of the large FOV visual system with the detailed daylight scene capability.

Ref. 6-1. Kron, G.J., Advanced Simulation in Undergraduate Pilot Training, AFHRL-TR-75-59 (111), Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio, October 1975.

Ref. 6-2. Young, L. R., "The Current Status of Vestibular System Models", Automatics, Vol. 5, pp. 369-383, Pergamon Press, 1969.

Ref. 6-3. Ashworth, B.R., A Seat Cushion to Provide Realistic Acceleration Cues for Aircraft Simulators, NASA TMX-73954, NASA, Washington, D.C. September 1976

Ref. 6-4. Curry, R. E., Hoffman, W. C., and Young, L.C., Pilot Modelling for Manned Simulation, AFFDL-TR-76-124, Vol. 1, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, December 1976.

(d) The relative requirements of the two crewmembers.

Items (a), (b), and (c) are discussed in the following paragraphs with reference to the application of each motion cueing module in providing the required cues.

The following discussion concentrates on the motion cueing requirements of the pilot. The relative requirements of the copilot/gunner are discussed in paragraph 6.3.

6.2 SYSTEM MODULES

The motion cueing system consists of three main elements:

- Seat motion system
- G-seat system
- Cockpit motion system

Each of these elements is discussed in the broadest terms in the following paragraphs for their application to the AH-64 simulation. The cueing effectiveness and the complexity of each are important considerations in the choice of design. Compatibility between the cueing sensations of each element must also be achieved, although this is an area in which little documentary evidence is available. It may be necessary, therefore, to utilize less than the maximum capability of each motion cueing module until more information is available on the optimum techniques of phasing in the cue from one module to another.

The approximate bandwidths of these three devices are shown in Figure 6-1.

The seat system is obviously limited in displacement to avoid destroying the pilot's geometrical relationship to the controls and, hence, to avoid spurious control movements.

The cockpit motion system is also amplitude limited simply because of physical size. In spite of the attenuation shown here, cockpit motion systems are not dead at frequencies of 10 Hz and above. Vibration representative of those encountered in the various operating regimes of the AH-64 can be produced in cockpit motion systems.

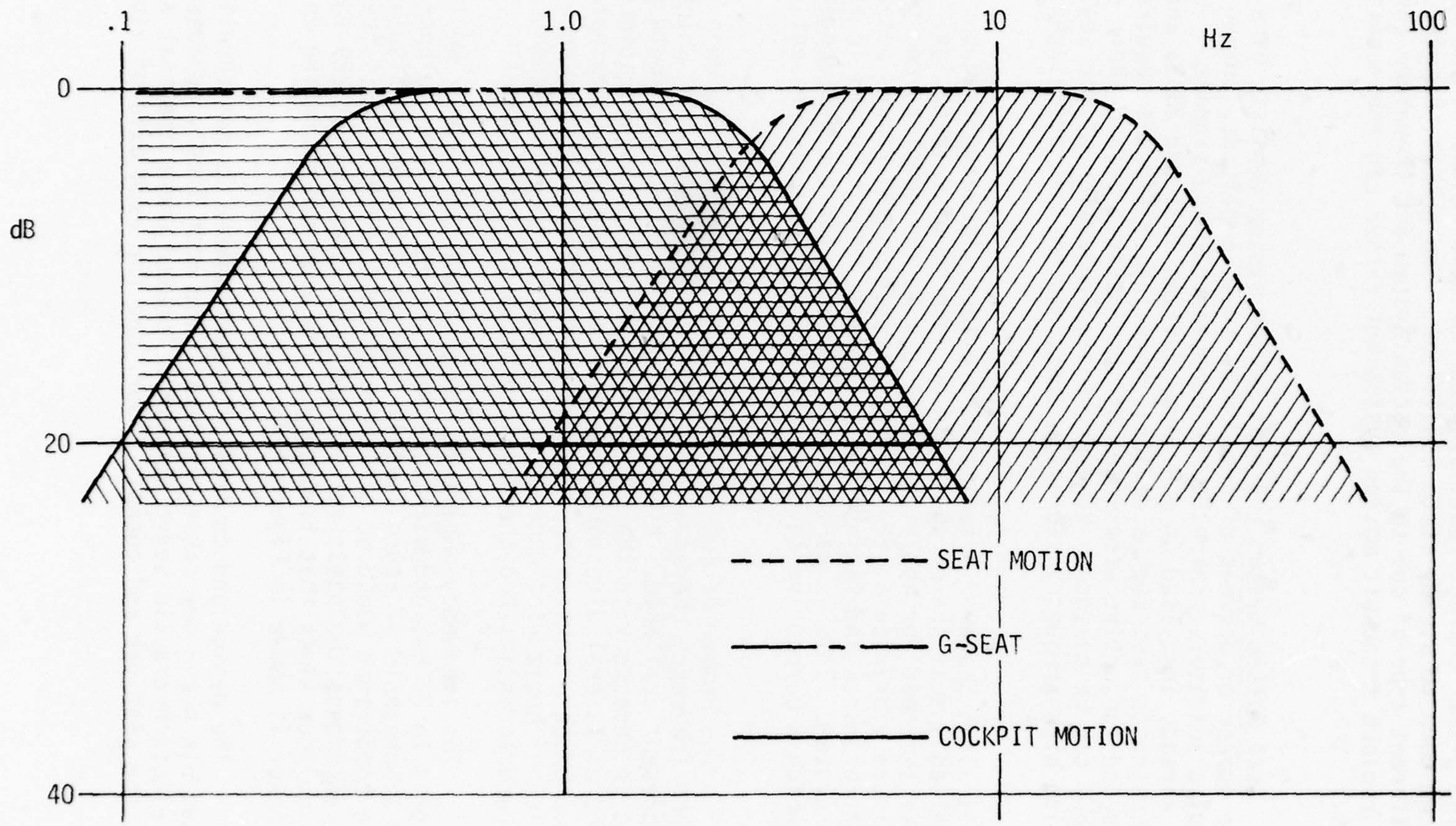


Figure 6-1. Bandwidths of Motion Cueing Modules

The g-seat characteristics appear to cover those of the cockpit motion system down to steady state conditions. The g-seat, however, produces a different type of cue to the motion system and therefore cannot completely replace a cockpit motion system but rather can enhance its effectiveness.

6.2.1 Seat Motion System. A seat motion system consists of a crew seat with a number of degrees of freedom of small amplitude, driven by electrohydraulic actuators controlled by computer command signals. Two examples are already installed on U.S. Army devices 1B31 and 2B33, and the USAF is planning to test such a device. More information is required on the performance and subjective assessment of such devices before their cost-effectiveness can be decided. However, a simple version of the seat, which could provide high frequency vibration cues, has obvious advantages.

6.2.1.1 Seat Shaker. A seat that provides vibration frequencies would be called a seat shaker and could be much simpler in design. It would remove the need for applying vibrations to the complete cockpit and hence eliminate vibration at the instructor station and remove potential problems of resonance and fatigue in the cockpit structure and in the visual projection system. This is particularly valuable for the helicopter simulation in which a perceptive level of vibration is usually present during flight.

The number of axes of vibration required depend upon the vibration and frequency characteristics of the helicopter, for which data is not at present available. Vibration in the vertical mode would probably be all that is necessary in the simulator, but horizontal vibrations in the fore-aft and/or lateral directions may have particular training value in order to reproduce a particular aircraft malfunction or performance limit. The provision of horizontal degrees of freedom is purely dependent upon the aircraft characteristics and the simulator training requirements.

The frequency-amplitude range of the seat shaker would be of the order of 3 to 20 Hz, and with a maximum acceleration up to approximately 0.5 g with a threshold of approximately 0.05 g. The maximum displacement under these conditions would be of the order of 0.5 inch. This frequency range will encompass the basic rotor rotational frequency at 289 rpm (4.8 Hz) and up to four times that frequency. The proposed operating envelope of the seat shaker is shown in Figure 6-2.

The design and control of a seat shaker is not complicated, although audible noise may cause problems. The most likely approach would be to use electrohydraulic servo actuators located under the seat and rigidly mounted to the seat pan and cockpit floor, one for each axis of vibration.

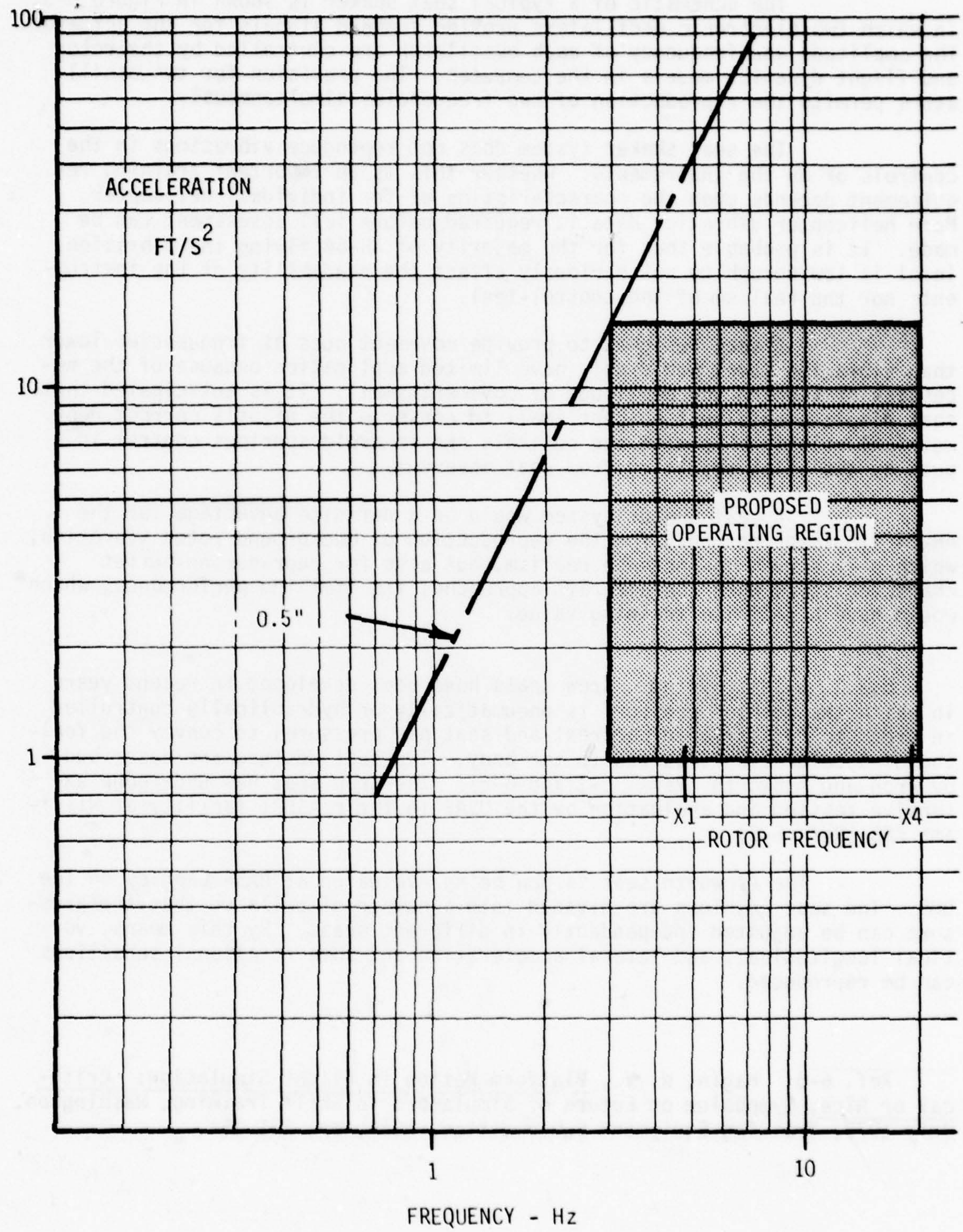


Figure 6-2. Seat Shaker Proposed Operating Region

The schematic of a typical seat shaker is shown in Figure 6-3, in which two electronic oscillators provide command signals for the actuator. The amplitude and frequency of each oscillator are controlled by the rotor and flight dynamics models in the computer. The provision for two oscillators permits the reproduction of two frequencies simultaneously.

The seat shaker system does not reproduce vibrations in the controls or on the instruments. Whether this is an important training requirement depends upon the characteristics of the individual helicopter. More helicopter vibration data is required before full assessment can be made. It is probable that for the majority of AH-64 flying the vibration level is low enough to not seriously affect the readability of the instruments nor the realism of the control feel.

A seat designed to provide movement cues at frequencies lower than vibration level would only have limited application because of the necessity of keeping the amplitude of movement small. It is anticipated that seat displacements must be kept small to conserve the pilot's correct geometrical relationship with the controls and to avoid spurious control inputs by the pilot resulting from seat movement.

A seat shaker system would be a definite advantage for the AH-64 simulator not only for the reproduction of background rotor vibration, which only serves to increase realism, but also for reproducing buffet characteristics when the aircraft approaches its limiting performance, which would have a definite training value.

6.2.2 G-Seat System. Crew seats have been developed in recent years in which the cushion pressure is pneumatically or hydraulically controlled in order to redistribute backrest and seat pan pressures to convey the feeling of acceleration imparted to the body. Two seat designs are described by Kron and Ashworth (Refs. 6-1 and 6-3). The Kron seat has undergone extensive testing and evaluation by the USAF in their ASUPT facility at Williams AFB (Ref. 6-5).

The Ashworth seat is now being evaluated at NASA Langley on the DMS. The seat cushions are divided into a number of cells so that the pressure can be adjusted independently in different areas. By this means, vertical longitudinal, and lateral acceleration and some rotational sensations can be reproduced.

Ref. 6-5. Hagin, W. V., Platform Motion in Flight Simulation: Critical or Nice, Symposium on Future of Simulators in Skill Training, Washington, July 1976, Training Equipment Subcommittee, NSIA, pp. 151-154.

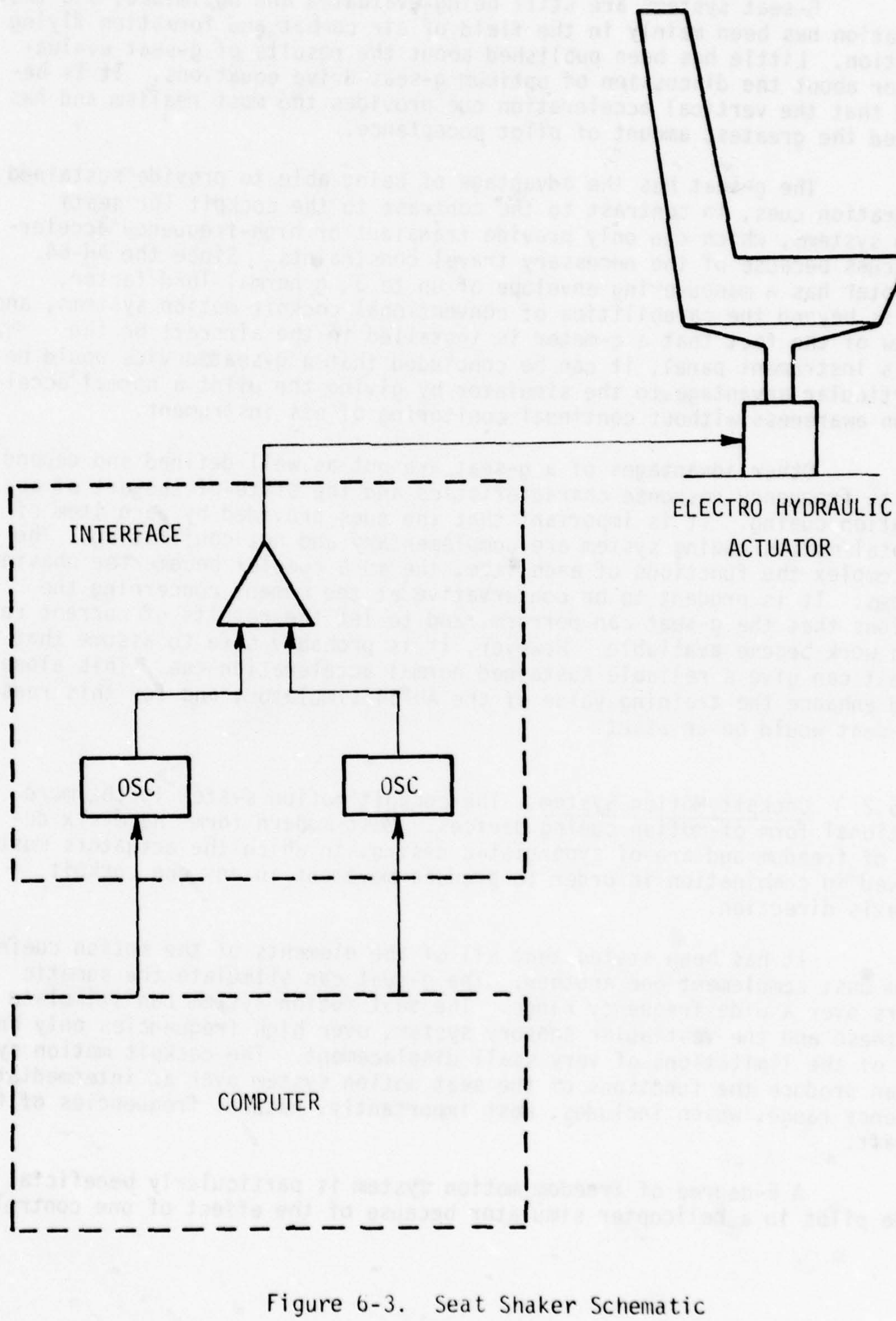


Figure 6-3. Seat Shaker Schematic

G-seat systems are still being evaluated and optimized, and their application has been mainly in the field of air combat and formation flying simulation. Little has been published about the results of g-seat evaluations or about the discussion of optimum g-seat drive equations. It is believed that the vertical acceleration cue provides the most realism and has received the greatest amount of pilot acceptance.

The g-seat has the advantage of being able to provide sustained acceleration cues, in contrast to the contrast to the cockpit (or seat) motion systems, which can only provide transient or high-frequency acceleration cues because of the necessary travel constraints. Since the AH-64 helicopter has a maneuvering envelope of up to 3½ g normal load factor, which is beyond the capabilities of conventional cockpit motion systems, and in view of the fact that a g-meter is installed in the aircraft on the pilot's instrument panel, it can be concluded that a g-seat device would be of particular advantage to the simulator by giving the pilot a normal acceleration awareness without continual monitoring of his instrument.

Other advantages of a g-seat are not as well defined and depend upon its frequency response characteristics and the state-of-the-art of acceleration cueing. It is important that the cues provided by each item of the total motion cueing system are complementary and not conflicting. The more complex the functions of each item, the more complex become the phasing problems. It is prudent to be conservative at the moment concerning the functions that the g-seat can perrorm, and to let the results of current research work become available. However, it is probably safe to assume that the seat can give a reliable sustained normal acceleration cue. This alone should enhance the training value of the AH-64 simulator, and for this reason the g-seat would be an asset.

6.2.3 Cockpit Motion System. The cockpit motion system is the more traditional form of motion cueing devices. Most modern forms have six degrees of freedom and are of synergistic design, in which the actuators must be moved in combination in order to produce movement in any one cockpit body axis direction.

It has been stated that all of the elements of the motion cueing system must complement one another. The g-seat can stimulate the somatic sensors over a wide frequency range. The seat motion system can stimulate both these and the vestibular sensory systems over high frequencies only because of the limitations of very small displacement. The cockpit motion system can produce the functions of the seat motion system over an intermediate frequency range, which includes, most importantly, natural frequencies of the aircraft.

A 6-degree of freedom motion system is particularly beneficial to the pilot in a helicopter simulator because of the effect of one control

intracting into more than one response axis. For instance, a pedal input at low speed induces yawing moment, sideforce, and possibly rolling moment.

The excursion requirements of a cockpit motion system are dependent upon the training requirements. As compared with conventional aircraft, the helicopter also has an additional collective pitch control, which gives direct control of vertical acceleration. The large normal acceleration envelope of the AH-64 also increases the need for good vertical acceleration cues from the motion system. Two motion system configurations are compared here, one with an increased heave excursion capability.

6.2.3.1 Motion Drive Equations. The techniques available for computing motion system command signals are reviewed by Conrad and Schmidt and by Sinacori (Refs. 6-6 and 6-7), and the current state-of-the-art is such that the choice of effective filtering parameters is well defined for a given motion system with typical constraints.

A typical motion drive equation block diagram for a transport aircraft is shown in Figure 6-4. The aircraft model accelerations at the center of gravity are used to initiate the motion command signals, following a transformation to the aircraft cockpit position. Low-frequency and steady-state accelerations can obviously not be reproduced fully on the motion base and are attenuated by second-order high-pass filtering. A transformation from the moving motion axes to earth, or base, axes ensures that the occupants of the simulator experience acceleration cues in the correct directions, and a washout algorithm eliminates long-term drift and maximizes the capability of the system to provide additional cues. The horizontal accelerations (x and y) are low-pass filtered into the cockpit pitch and roll commands to provide steady state horizontal acceleration sensations.

Referring to Equation (6-1) a typical second-order high-pass filter is given as

$$\frac{\ddot{x}_o}{\ddot{x}_i} = \frac{\tau^2 s^2}{1 + 2\zeta\tau s + \tau^2 s^2} \qquad (6\text{-}1)$$

Ref. 6-6. Conrad, B., and Schmidt, S., A Study of Techniques for Calculating Motion Drive Signals for Flight Simulators, NASA CR-114345, July 1971.

Ref. 6-7. Sinacori, J., A Practical Approach to Motion Simulation, AIAA Visual and Motion Simulation Conference, Paper 73-931, September 1973.

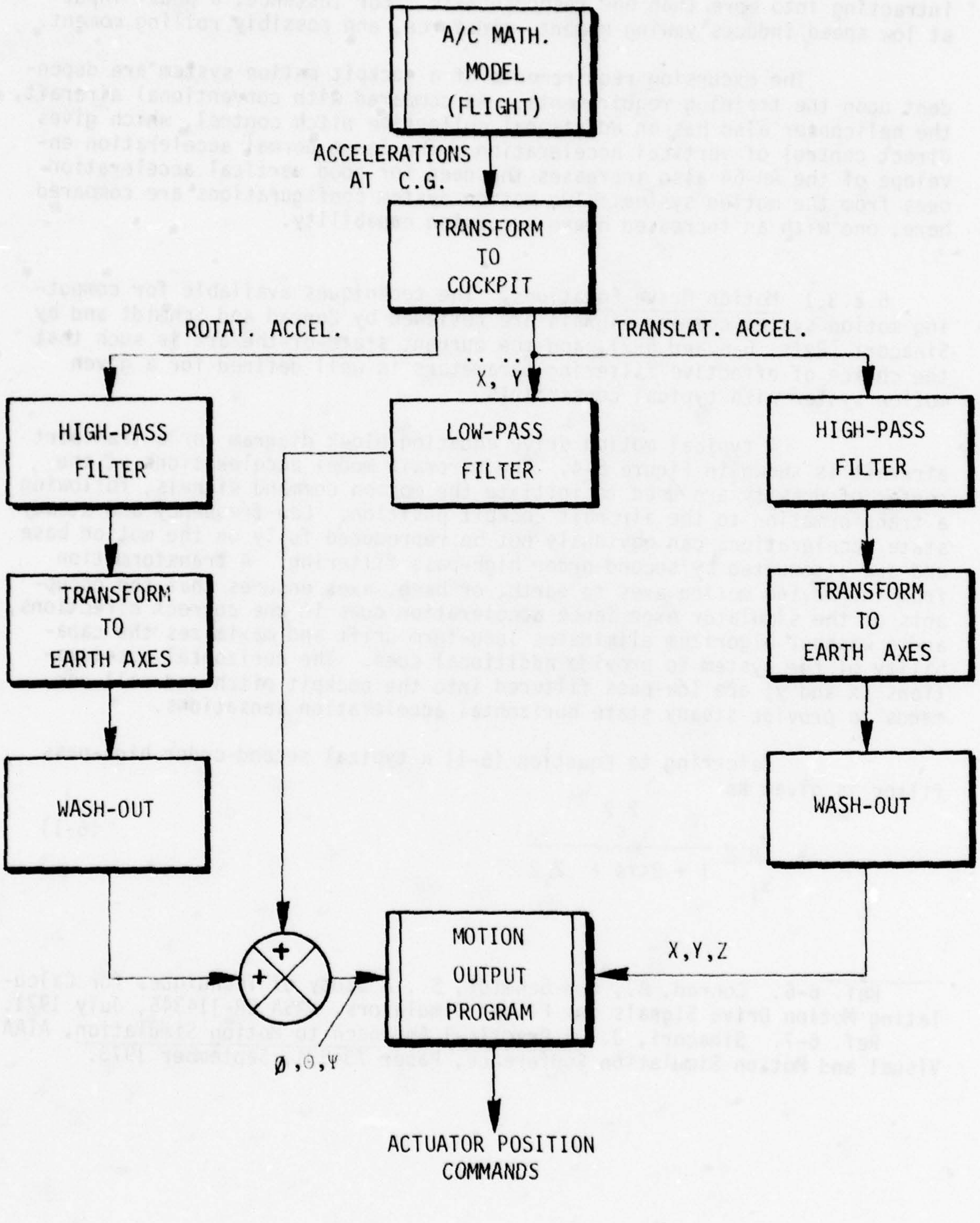


Figure 6-4. Overview of Motion Drive Equations

It is necessary that the time constants (τ) and the damping factors (ζ) be independently adjustable for each degree of freedom. The time constants for conventional six-axis motion systems are, typically, in the range of 0.3 second to 3.0 seconds.

The time history response to a step input for such a filter is shown in Figure 6-5. This response is computed numerically at an iteration of 50 milliseconds. The input represents a step input of acceleration applied to the aircraft dynamic model, and the output shows the acceleration imparted to the simulator cockpit. It can be seen that the step changes of acceleration passes straight through the filter, followed by decay in the magnitude and a slight overshoot. In the steady state, the motion is displaced from its original position by an amount.

$$x_o = \tau^2 \ddot{x}_i \qquad (6\text{-}2)$$

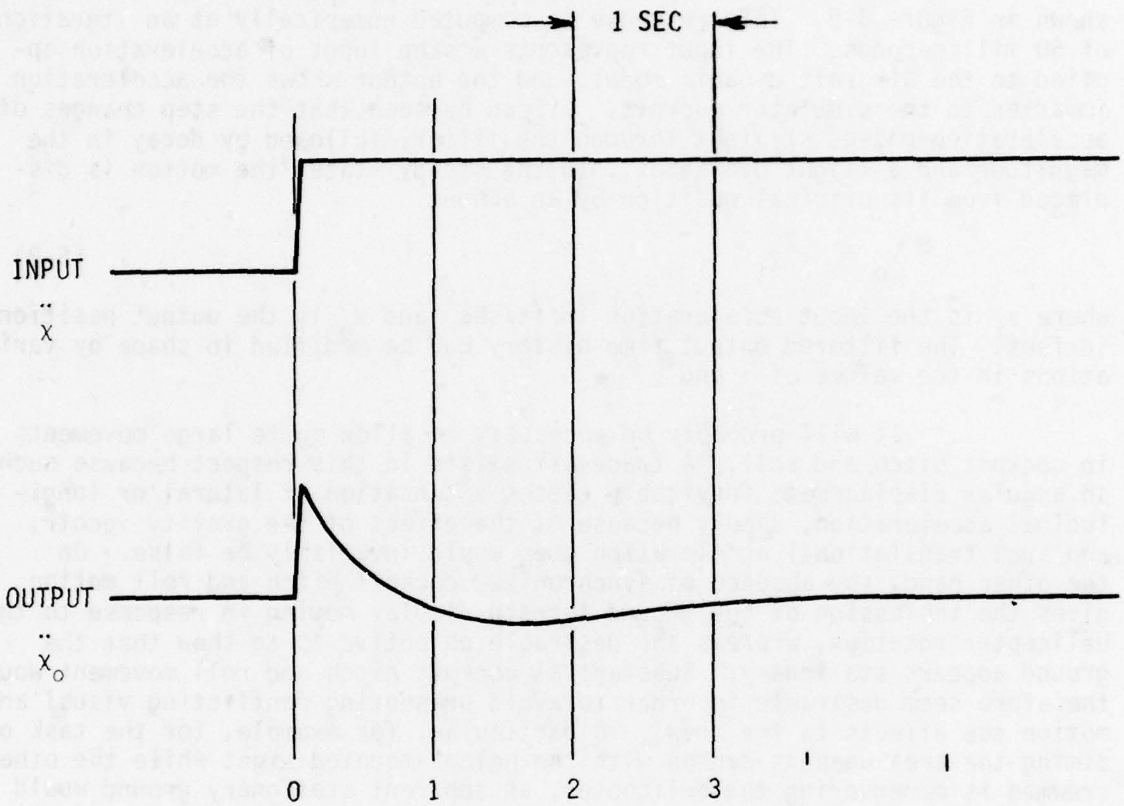
where $\ddot{x}_i$ is the input acceleration in ft/sec^2 and x_o is the output position in feet. The filtered output time history can be modified in shape by variations in the values of τ and ζ.

It will probably be necessary to allow quite large movements in cockpit pitch and roll. A trade-off exists in this respect because such an angular displacement inevitably causes a sensation of lateral or longitudinal acceleration, simply because of the effect of the gravity vecotr, and such translational acceleration cues would invariably be false. On the other hand, the absence of synchronized cockpit pitch and roll motion gives the impression of the ground terrain display moving in response to the helicopter rotation, whereas the desirable objective is to show that the ground appears stationary. Substantial cockpit pitch and roll movement would therefore seem desirable in order to avoid presenting conflicting visual and motion cue effects to the crew. In particular, for example, for the task of aiming the area weapons cannon with the helmet-mounted sight while the other crewman is maneuvering the helicopter, an apparent stationary ground would be important.

There is also a need for good simulation of heave, primarily because of the direct effect of the collective pitch control.

The lateral and longitudinal degrees of freedom would probably have a small cue function as a result of pilot control inputs, but this would be important under turbulence conditions and in weapon firing.

The software itself can, of course, be adjusted at a much later time. But these considerations can affect the choice of hardware design.



DAMPING FACTOR = .7

TIME CONSTANT = .7

Figure 6-5. Acceleration Time History with Second Order Filtering

6.2.3.2 6-Degree of Freedom System. Visual system considerations dictate a separate crew compartment for both the pilot and copilot/gunner. This approach implies the use of two separate but synchronized motion systmes with a coordinate transformation required for the second because of the difference in aircraft seat location between the pilot and copilot. In this section, it is assumed that integrated crew training will be implemented; however, with separate facilities, the possibility exists of isolating the pilot from the copilot, providing independent crew training.

The essential performance requirements of the motion system are:

- Resolution: the ability to respond accurately to small amplitude inputs.
- Responsiveness: the ability to respond to input commands without noticeable lag.
- Smoothness: the absence of self-generated or spurious disturbances.
- Stability: the absence of mechanical or electrohydraulic resonances which would adversely affect simulation.

Generally, good simulation depends on judicious compromise between fidelity and stability. A high closed-loop gain generally tends to improve fidelity as indicated by frequency response bandwidth and immunity to external disturbances; however, an excessive loop gain will result in ringing due to sustained oscillations. The use of force feedback and the careful selection of servo valve characteristics allow gain to be increased while maintaining or improving stability. The quality of the overall system depends on the final tuning of the motion system, the selection of gains for position, velocity and force feedback, and the tuning of the associated compensators and filters. At the present time, there are no generally accepted indices of motion system performance so that final tuning is governed largely by feel and experience. There are, however, several parameters which must be maximized to achieve good simulation, including motion travel, system frequency response, and the ability of the motion system to faithfully respond to low amplitude inputs with minimal self-induced disturbance. Motion travel is determined as a compromise between the cost, stiffness, and maintainability advantages of a compact system opposed to the increased acceleration envelope of a larger motion system. In any case, the available travel should be compatible with the acceleration and velocity limits.

For the second performance measure, frequency response, experience has shown that attempts to maximize bandwidth are misdirected in terms of overall system performance. High-frequency components are not

normally significant in flight simulation, and optimal control is more dependent on smoothness. More significant for simulation is the elimination of low-frequency structural resonances.

The reduction of noise in acceleration is an important design goal, particularly in the case of random discontinuities which can be interpreted as false motion cues.

6.2.3.2.1 Horizontally Mounted Motion System. The CAE horizontal motion system is a 6-degree of freedom electrohydraulic servo system capable of providing realistic pitch, roll, and yaw rotations, plus lateral, longitudinal, and vertical translations in response to electrical command signals from the computer interface.

The configuration arrangement is shown in Figure 6-6. The CAE design approach reflects state-of-the-art techniques with due consideration given to simplicity, weight, reliability, and maintainability requirements, while maximizing performance under the constraint that safety must be maintained. The motion system is similar structurally to other CAE systems of proven performance, reliability, and safety. The hydraulic power supply hoses and servoactuators are sized to provide sufficient flow capacity and pressure to generate accelerations and velocities compatible with the motion envelope. The cradle frame is separable from the crew compartment so that the motion system can remain intact and be operated independently. The motion system specified performance requirements take into account the normal weight of the crew compartment complete with instructor station, visual display system, and two personnel, plus 500 pounds.

Improvement of the present CAE horizontal motion system is the subject of a research and development program in progress at CAE. Recent developments include the following:

(a) The use of pressure feedback to improve control, and friction reduction in the hydraulic actuator to improve smoothness.

(b) The use of asymmetric valves to reduce discontinuities at motion reversal and to improve software simulation techniques.

Further improvements including the use of larger jacks to increase the frequency of basic structural and hydraulic resonances, weight reduction and simplified construction are being tested. The use of hydrostatic bearings in the servojacks to reduce friction is also being tested.

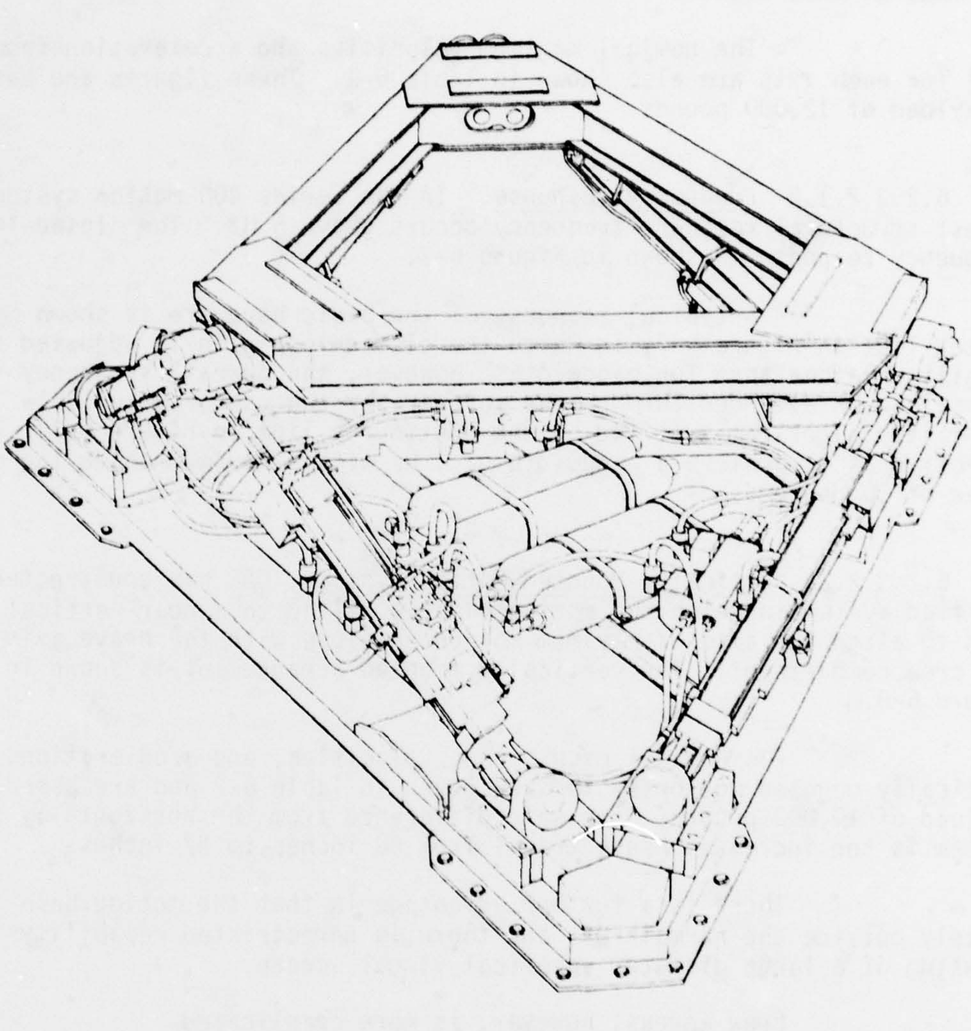


Figure 6-6. Horizontally Mounted Six-Degree-of-Freedom Motion System

6.2.3.2.1.1 Motion Envelope. The nominal maximum excursions of the motion system are listed in Table 6-1. The values listed are measured independently in each axis about the neutral position, except for the values for the lateral and longitudinal motions, which are not about the neutral heave position. the motion system can achieve any combination of 20% of the maximum excursions.

The nominal maximum velocities and acceleration from neutral for each axis are also shown in Table 6-1. These figures are based on a payload of 12,000 pounds.

6.2.3.2.1.2 Frequency Response. In the Series 400 motion system, the lowest structural resonant frequency occurs above 5 Hz. The closed-loop frequency response is shown in Figure 6-7.

A typical response of the basic hardware is shown by a dotted line in Figure 6-7, in which the closed-loop gain is adjusted for stability rather than for bandwidth. However, the overall frequency response can be extended through the software by the use of a suitable lead-lag filter algorithm typified by the continuous line in Figure 6-7. The objective is to achieve a bandwidth of 1 Hz with a maximum phase lag of the order of 30 degrees.

6.2.3.2.2 Vertically Mounted Motion System. CAE has constructed a modified system in which the motion base is tilted to a near vertical position to align the axis of maximum motion envelope with the heave axis of the crew compartment. The vertically mounted arrangement is shown in Figure 6-8.

The nominal excursions, velocities, and accelerations of the vertically mounted motion system are given in Table 6-2 and are based on a payload of 10,000 pounds. The main difference from the horizontally mounted system is the increased heave travel from 60 inches to 87 inches.

There is a further advantage in that the motion base is completely outside the normal FOV, and there is unrestricted capability for the mounting of a large diameter spherical visual screen.

Crew access, however, is more complicated.

A possible reconfiguration of this system for the use of two cockpits is shown in Figure 6-9. This would retain the benefits of the system while making more efficient use of space.

TABLE 6-1. HORIZONTALLY MOUNTED MOTION SYSTEM NOMINAL PERFORMANCE

AXIS	DISPLACEMENT	VELOCITY	ACCELERATION
pitch	$\pm 25^{o}$	$\pm 20^{o}$/sec	$\pm 150^{o}/sec^2$
roll	$\pm 20^{o}$	$\pm 20^{o}$/sec	$\pm 200^{o}/sec^2$
yaw	$\pm 30^{o}$	$\pm 25^{o}$/sec	$\pm 150^{o}/sec^2$
vertical	±30 inches	±27 in/sec	±1.0g
lateral	±40 inches	±36 in/sec	±.8g
longitudinal	±46 inches	±36 in/sec	±.5g

TABLE 6-2. VERTICALLY MOUNTED SYSTEM NOMINAL PERFORMANCE

AXIS	DISPLACEMENT	VELOCITY	ACCELERATION
pitch	$+36/-26^{o}$	23^{o}/sec	$170^{o}/sec^2$
roll	$\pm 23^{o}$	20^{o}/sec	$170^{o}/sec^2$
yaw	$\pm 25^{o}$	18^{o}/sec	$170^{o}/sec^2$
vertical	+51/-36 inches	±35 in/sec	±.8g
lateral	±44 inches	±30 in/sec	±.8g
longitudinal	±33 inches	±18 in/sec	±.8g

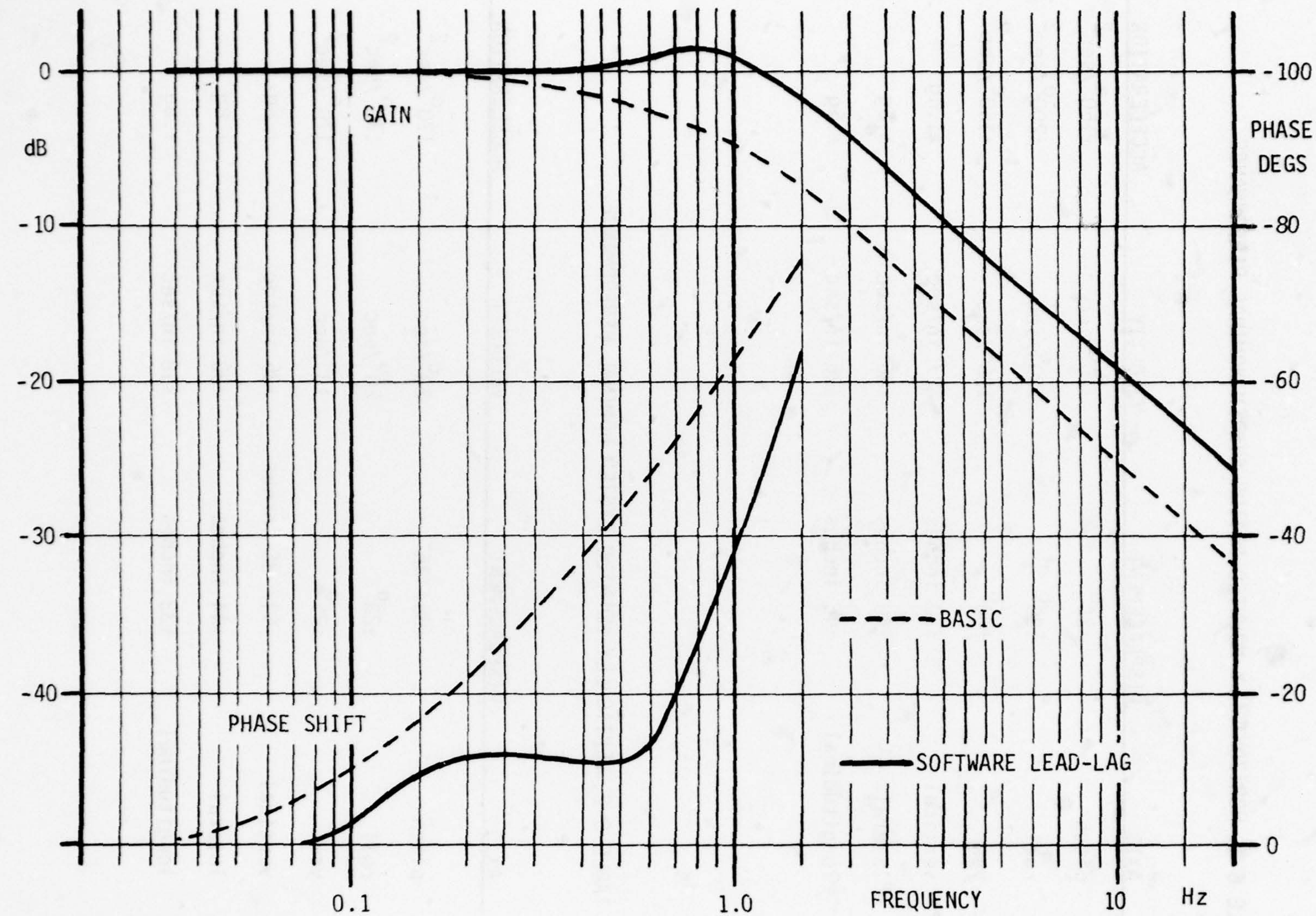


Figure 6-7. Cockpit Motion System Frequency Response

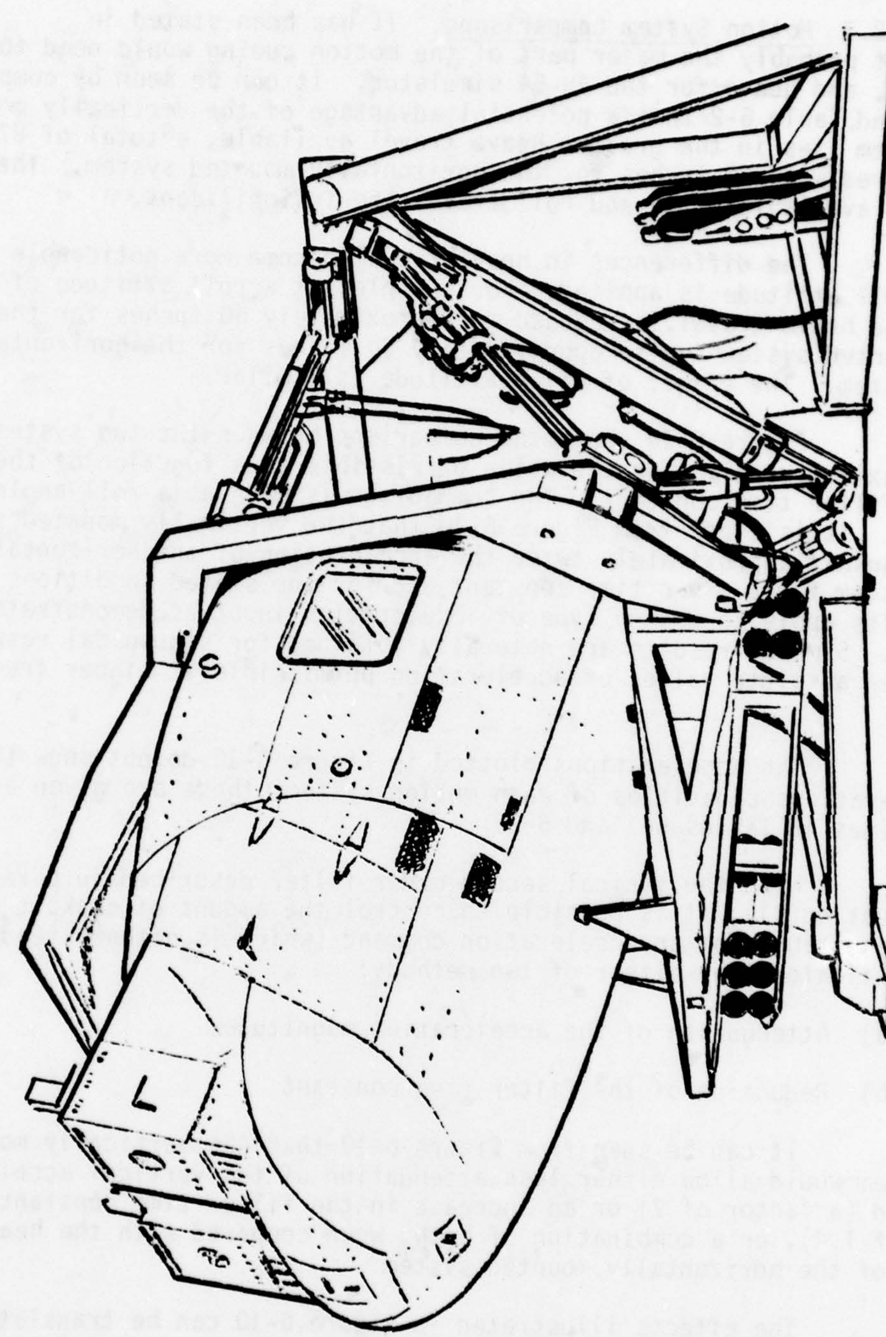


Figure 6-8. Vertically Mounted 6-Degree of Freedom Motion System

6.2.3.2.3 Motion System Comparisons. It has been stated in 6.2.3.1 that probably the major part of the motion cueing would need to be in pitch, roll, and heave for the AH-64 simulator. It can be seen by comparing Table 6-1 and Table 6-2 that a potential advantage of the vertically mounted motion system lies in the greater heave travel available, a total of 87 inches, compared with 60 inches for the horizontally mounted system. The differences in available pitch and roll travel are insignificant.

The differences in heave travel become more noticeable as pitch or roll attitude is applied. For example, at a roll attitude of 10 degrees, the heave travel is reduced to approximately 60 inches for the vertically mounted system and to approximately 30 inches for the horizontally mounted system. The effect of pitch attitude is similar.

Figure 6-10 shows the comparison between the two systems in terms of maximum vertical acceleration permissible as a function of the second-order filter time constant. The comparison is made at a roll angle of 10 degrees. It is clear from Figure 6-10 that the vertically mounted system can transmit approximately twice the acceleration of the horizontally mounted system for a given time constant and for the stated conditions. These results apply to a step type of acceleration input as demonstrated in Figure 6-5. Similar results are naturally obtained for sinusoidal response, with greater absolute values of acceleration permissible at higher frequencies.

The accelerations plotted in Figure 6-10 do not show the maximum accelerations capacities of each motion system; these are given as nominal values in Tables 6-1 and 6-2.

With the typical second-order filter described in paragraph 6.2.3.1 (equation 11), it is possible to control the amount of cockpit displacement resulting from an acceleration command (which is either steady state or oscillatory) by either of two methods:

(a) Attenuation of the acceleration magnitude

(b) Reduction of the filter time constant

It can be seen from Figure 6-10 that the vertically mounted motion system would allow either less attenuation of the vertical acceleration command (a factor of 2) or an increase in the filter time constant (a factor of 1.4), or a combination of both, when compared with the heave capability of the horizontally mounted system.

The effects illustrated in Figure 6-10 can be translated to the cockpit motion system bandwidths (Figure 6-1). The improvement given by the vertically mounted system, in the heave direction only, is to therefore reduce the minimum frequency boundary by a factor of 0.7 on frequency. However, in order to give a real improvement in vertical acceleration cue, by

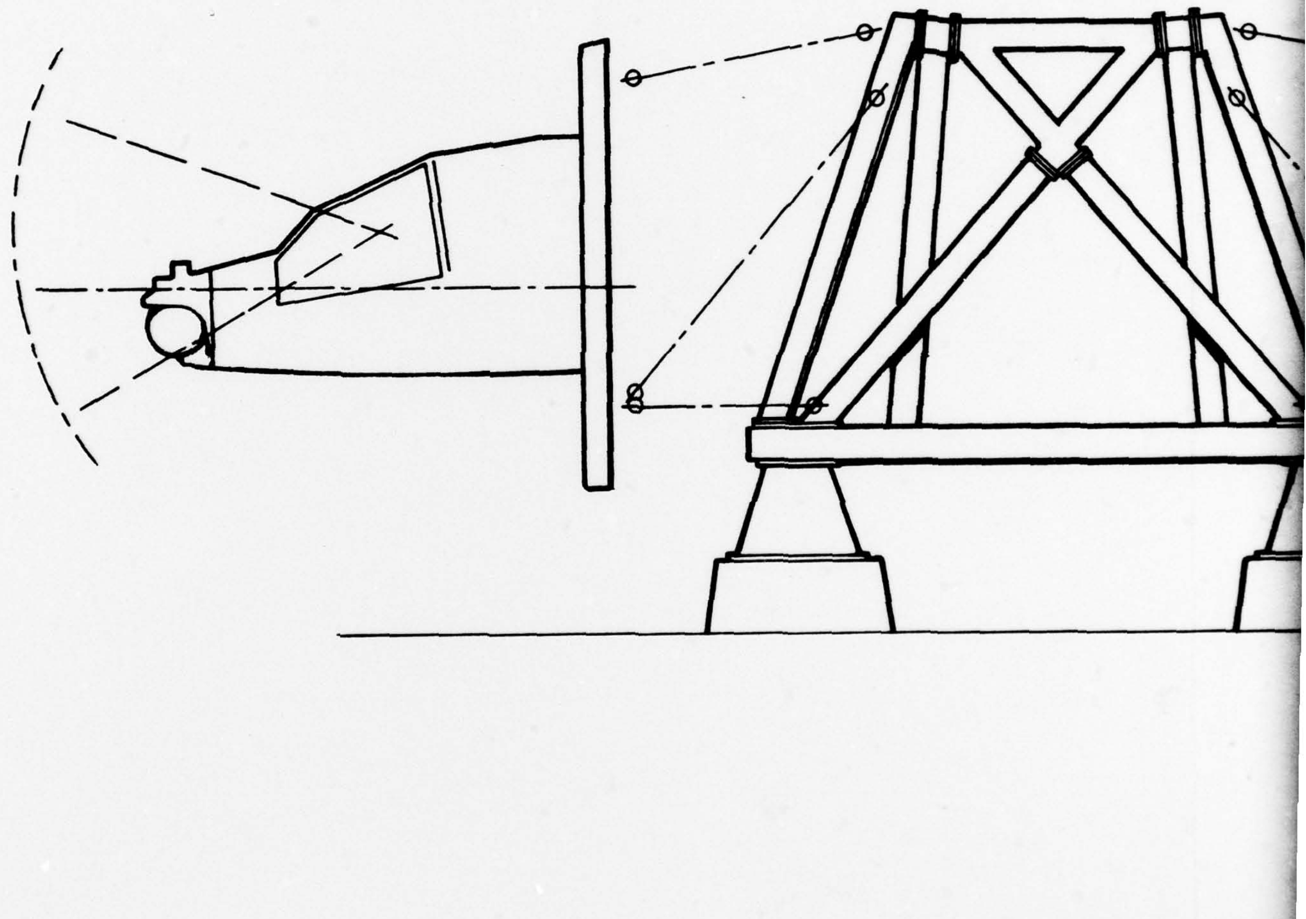
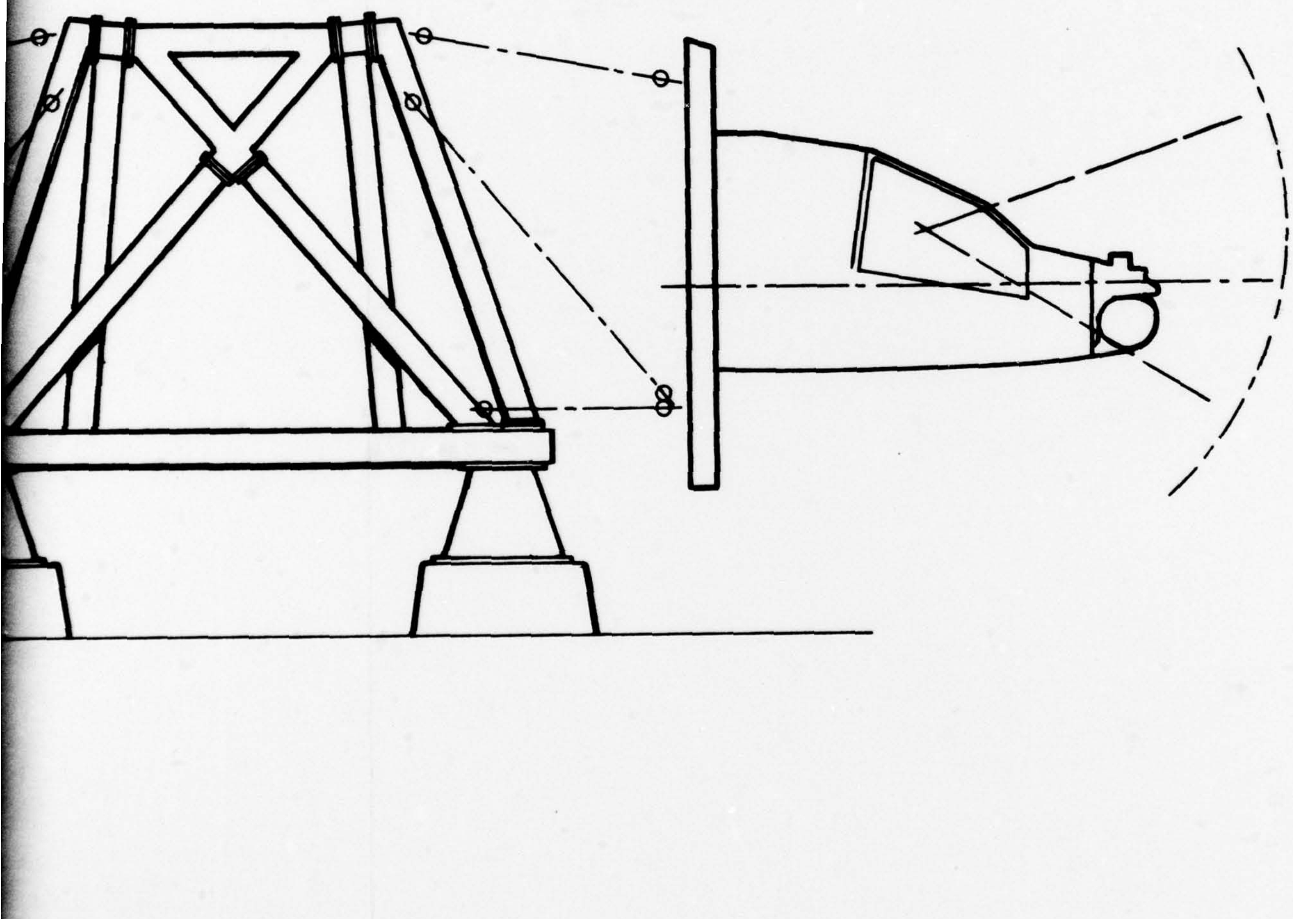


Figure 6-9 Two-Cockpit Vertically Mounted Motion System



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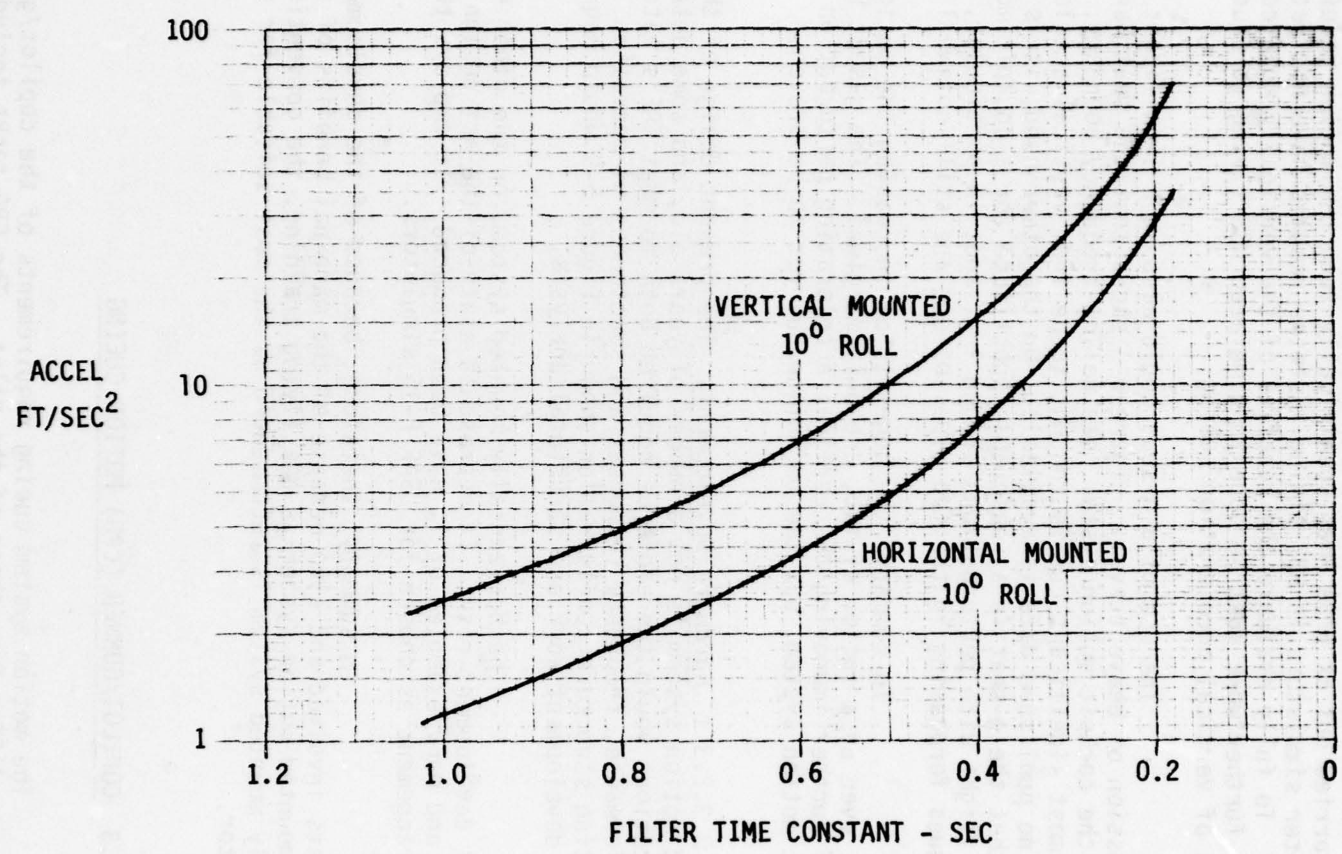

Figure 6-10. Acceleration Limit With Second-Order Filtering

reducing the low-frequency boundary to less than 0.1 Hz (Figure 6-1), a travel increase of at least a factor of 10 would be required. Research is being carried out at NASA Ames specifically into the motion requirements of helicopter simulators in NOE flying, but the results have not yet been published. To fully evaluate the benefits of the vertically mounted motion system, further work must be done in simulated NOE flying to study the effects of vertical acceleration cueing.

The use of a g-seat could also be a significant factor in a discussion of heave travel. Figure 6-1 shows that the seat bandwidth, unlike the cockpit motion system, has no low-frequency boundary. Also, the seat's most significant cue is thought to be from vertical acceleration, although no published data is available. On the other hand, it is by no means clear that the g-seat is a reasonable substitute for a cockpit motion cue during flight with perturbations around 1 g, and, in particular, the techniques forphasing in the two types of cue are still not well defined.

In summary, the benefits of increasing the motion system travel, even by a factor of two, are only marginal. The g-seat has the potential of further improving the vertical acceleration perturbation cue from the cockpit motion system, but the technique has yet to be proven.

6.2.3.2.3.1 Hardware Development. The present design of the vertically mounted motion system is now a number of years old, and some detailed design modifications would therefore be required both to meet CAE's latest standards of preformance, frequency response, and smoothness of operation. Also, the supporting structure configuration shown in Figure 5-9 would require significant development work and structural analysis.

The horizontally mounted system, on the other hand, has minimal development risk. It represents state-of-the-art design and performance, and many examples of it have been produced. It employs the mechanical arrangement as chosen for USAF F-15 simulators.

In summary, therefore, because of the development effort and costs involved and also because of the marginal benefits of the vertically mounted motion system in NOE flying training, the conventional horizontally mounted system is recommended as the most suitable for the AH-64 simulator.

6.3 COPILOT/GUNNER (CPG) MOTION CUEING

The motion system cueing requirements of the copilot/gunner crewmember may differ from those of the pilot. The CPG tasks include the following four major items:

(a) Navigation

(b) Target acquisition and identification

(c) Weapon firing

(d) Backup pilot

Since the visual system design dictates a separate cockpit for each crewmember, with each cockpit mounted upon its own motion base, then it is possible to consider the motion cueing requirements of each crewmember individually. The motion drive equations can be optimized, therefore, for the primary task of each crewmember.

Adjustment of the motion drive equations should be made to allow for the different positions of each crewmember relative to the aircraft center of gravity.

The motion system cueing for the pilot requires coordination with the control responses and with the visual scene, so that he will receive sufficient motion sensations to enable him to fly the simulator with the same degree of accuracy as the helicopter under a variety of environmental and malfunction conditions. The motion drive equations must therefore be designed largely to cause motion cueing response in all axes to his control inputs.

The major tasks of the CPG have been listed above. For all tasks except (d), the CPG must function as efficiently as in the aircraft while being subject to motion cues from the simulator, which is not under his direct control.

For the navigation task, the motion system would inform him of helicopter direction changes, with his head down, and must also avoid the occurrence of unnatural motion sickness. The latter phenomenon could be a significant problem for the CPG in the AH-64 simulator, since he would need to continually tilt his head in order to map read within the cockpit as well as establish local landmarks outside the cockpit while enroute.

The target acquisition and identification task, which would mainly involve the use of the TADS boot display screen, is an uncertain problem as far as motion cues are concerned. It is thought that the CPG's performance of this task is probably influenced by his being able to anticipate when the target (or target area) will disappear from view. This will occur when the pilot allows the helicopter to drop behind hills or trees, a situation outside the direct control of the CPG.

With his view restricted to that of the boot display, the CPG's only awareness of the helicopter's flight path is through his motion and audio sensors, and he must therefore use these to anticipate when the target will be observed. It is thought that sufficient motion cues for this task would be provided by the cockpit motion system and the seat shaker, the lat-

ter to transmit recognizable changes in vibration characteristics. If the stabilized sight system of the TADS display were inoperative, the CPG's performance in manual tracking would be greatly influenced by cockpit pitch, roll, and yaw motion. It is not certain at this stage, however, whether this is a feasible training task.

In weapon firing, the one area in which motion cueing would have a significant effect on performance is in the use of the area weapons cannon through the helmet-mounted sight. When using this weapon in the aircraft, the CPG task is mainly to keep his head oriented in space in order to track the target while the aircraft is maneuvered about by the pilot. This would be a completely different task in a simulator with no motion cueing; it would require the CPG to move his head orientation in space in order to track the target as the ground display moves in response to the helicopter maneuvers. With realistic simulator motion cueing, the crew performance of this task could be similar to that of the aircraft. The motion drive equations, however, may need to be different from those of the pilot for optimum performance because it is anticipated that more emphasis may be needed on the rotational cues.

In the task of backup pilot, the CPG would require motion cueing drive equations similar to those for the pilot after making allowance for their different positions in the aircraft.

6.4 CONCLUSION

It will be important to provide realistic motion cueing simulation for the crew occupants of the AH-64 simulator.

A seat shaker system with a vertical vibration capability will be required for the pilot. Human operators appear to be sensitive to amplitude and frequency of high-frequency vibration but not to direction. Horizontal vibration will therefore not be required. Similarly, rotational and non-vibratory seat motions will not be required. The advantages of a seat shaker for the CPG are less well defined. It is recommended, however, that one be provided that has vibration capabilities similar to those of the pilot's seat shaker.

A g-seat with vertical acceleration cue capability will be of value to the pilot in maneuvering flight. The value of g-seat cues in other axes is dependent upon the drive equations and upon the results of further research work for their optimization. A g-seat is unlikely to be of value to the CPG and is not recommended.

A cockpit motion system is necessary to provide short-term acceleration responses to control inputs, so that the pilot can give a realistic performance in the simulator. The cockpit motion system is also an advantage to both crewmen in avoiding motion sickness and in assisting in realistic weapon aiming. It could be valuable to the CPG also while using the TADS boot display system.